VOLUME XXIII NUMBER 7

THE

JOURNAL OF GEOLOGY

OCTOBER-NOVEMBER 1915

REVISION OF PRE-CAMBRIAN CLASSIFICATION IN ONTARIO[1]

WILLET G. MILLER AND CYRIL W. KNIGHT
Ontario Geological Survey, Toronto, Canada

The pre-Cambrian rocks of Ontario have undergone much scrutiny during the last seventy years. At the very beginning of his labors as provincial geologist of Canada (Ontario and Quebec) in 1843 Logan confirmed the observations made by other investigators, that the oldest fossiliferous rocks lie unconformably on a vast crystalline series. By degrees he and his associates, working in the regions adjacent to the Ottawa River and to the north shore of Lake Huron respectively, came to the conclusion that these ancient rocks as regards their age relations are divisible into two great groups, the older of which was named the Laurentian and the younger the Huronian.[2] Other pre-Cambrian rocks were studied on Lake Superior.[3] To these was given the name Upper Copper-bearing Rocks of Lake Superior. They were divided into two groups, the upper of which has come to be known as the Keweenawan and the lower as the Animikie.

[1] This paper was presented in abstract at the meeting of the Geological Society of America, December, 1914.

[2] *American Association for the Advancement of Science*, 1857; *Geology of Canada*, 1863, pp. 22 f.

[3] *Geology of Canada*, 1863, pp. 67 f.

In conformity with the views of the time, Logan and his associates considered the Laurentian to be made up essentially of metamorphosed sedimentary material. With the passing of the years, the Laurentian came to be looked upon as separable into

FIG. 1.—Geological sketch map of Ontario

three groups: (1) Lower Laurentian or Ottawa series, consisting essentially of granite gneiss; (2) Middle Laurentian or Grenville series, consisting of crystalline limestone and other rocks; and (3) Upper Laurentian or Norian. From the Laurentian groups was first taken the Upper Laurentian, which was proved to be not of sedimentary origin but an intrusive.[1] Afterward the Grenville

[1] *Neues Jahrb.*, Beilage Band 8, 1893, pp. 419–98.

was taken away and the name Laurentian came to stand only for granite and gneiss of undoubted igneous origin, older than the so-called Huronian sediments.[1]

CLASSIFICATIONS NOW IN USE

The need for a revision of the classification and nomenclature of the pre-Cambrian rocks has been felt from time to time as knowledge concerning them has increased.

Table I shows the classification that has been adopted by the authors.[2] Like all other classifications it will be subject to revision when a more perfect understanding of the relations of the rocks is acquired.

In Table II are given the classifications employed by several other authors.

LAURENTIAN AND HURONIAN

Logan, himself, when introducing the names Laurentian and Huronian said: "These local names are, of course, only provisional, devised for the purpose of avoiding paraphrastic or descriptive titles, the use of which had been found inconvenient, and they can be changed when more important developments, proved to be the equivalents of the series, are met with elsewhere."[3] Hence, when it is found advisable to change the classification or to discard the now historic names, looked on by Logan as being only provisional, mere sentiment should not be permitted to stand in the way. In most cases it is better to discard a name rather than employ it in a new sense.

As shown in a preceding paragraph, the term Laurentian is now used in a much-restricted sense and, as will be seen from the following pages, different meanings are attached to it by various authors. The earlier literature in which Laurentian rocks were described has become almost unintelligible.

Much confusion has arisen also through the employment of the classic name Huronian, especially with the prefixes Upper, Middle, and Lower, in different senses. The term Lower Huronian, for example, has been applied indiscriminately to certain rocks

[1] Report of International Committee, *Jour. Geol.*, February-March, 1905.

[2] *Ont. Bur. Mines*, XXII, Part II, Appendix.

[3] *American Association for the Advancement of Science*, 1857.

that lie below one of the greatest known unconformities, that between the Timiskamian and Animikean of our classification, as well as to those above it. Again, rocks have been classed as Upper Huronian, or Animikie, which have not been proved to be

TABLE I

PRE-CAMBRIAN

KEWEENAWAN	
Unconformity	
ANIMIKEAN	Under this heading the authors place not only the rocks that have heretofore been called Animikie, but the so-called Huronian rocks of the "classic" Lake Huron area, and the Cobalt and Ramsay Lake series. Minor unconformities occur within the Animikean.
Great unconformity	
(ALGOMAN granite and gneiss)	Laurentian of some authors, and the Lorrain granite of Cobalt, and the Killarney granite of Lake Huron, etc.
Igneous contact	
TIMISKAMIAN	In this group the authors place sedimentary rocks of various localities, that heretofore have been called Huronian, and the Sudbury series of Coleman.
Great unconformity	There is no evidence that this unconformity is of lesser magnitude than that beneath the Animikean.
(LAURENTIAN granite and gneiss)	
Igneous contact	
LOGANIAN { Grenville (*Sedimentary*) / Keewatin (*Igneous*) }	The authors have found the Keewatin to occur in considerable volume in southeastern Ontario and have determined the relations of the Grenville to it.

different in age from certain so-called Lower and Middle Huronian. It may be added that for many years the Keewatin also was called Lower Huronian. Even at the present time when making use of the name Huronian, in order to secure clearness, it is necessary to say in what sense the name is employed, whether in that of the United States Geological Survey or in that of Coleman or Lawson

et al. Owing to the confusion that has arisen in connection with the use of the term the authors think it well to discard it.

Among those, including Coleman, Collins, and the authors, who have studied during recent years the pre-Cambrian rocks of the Lake Huron–Lake Timiskaming region, there is agreement as to most of the age relations, as will be seen from the classifications on a following page, but different nomenclatures are employed.

As to facts, the chief difference in opinion between Coleman and the authors is in regard to the relations among what he calls the Lower and Upper Huronian and the Animikie, and what we call collectively the Animikean. It is agreed that the Cobalt series, the Ramsay Lake series of Sudbury, and the usually flat-lying sediments of the classic area of Lake Huron are of the same age. But in Coleman's opinion, as shown in his table, the sediments of the Sudbury basin, the so-called Animikie series, are younger than the Ramsay Lake series, which he classes as Lower Huronian. But no discordance has been proved to exist between the Ramsay Lake series and the Animikie of the near-by Sudbury basin. For this and other reasons the authors class the Ramsay Lake series and the Animikie together as the Animikean. In this they are supported by investigations made by Van Hise and Seaman, who say: "About half a mile east of Sudbury they found a breccia or conglomerate [Ramsay Lake series] similar in every way to that seen at Onaping [Animikie series of Sudbury basin] resting on the eroded edges of Huronian [Timiskamian] and containing fragments of it."[1]

Beginning with the bottom of the columns of the two classifications, it will be seen that Coleman has accepted, provisionally at least, our interpretation of the relations of the Keewatin and the Grenville, described in a recent report.[2]

As is shown by Table II, Coleman and Collins use the name Sudbury series or Sudburian for the rocks which we call Timiskamian. But Timiskamian has priority as it was employed by the Ontario Bureau of Mines for rocks that occur at various points over an area at least 5,000 square miles in extent before the term "Sudburian" was introduced.[3] Moreover, since Logan first

[1] *U.S. Geol. Survey Bull.* 360, p. 425.

[2] *Ont. Bur. Mines*, XXII, Part II.

[3] *Eng. and Min. Jour.*, September 30, 1911, p. 648.

studied his "Huronian" rocks on Lake Timiskaming, the name Timiskamian is appropriate for a part of them. Further, the name Sudburian is likely to be confused with sudburite, a name applied to certain basic igneous rocks at Sudbury that intrude the Timiskamian but are older than the Algoman granite and gneiss.[1] It may be added that basic rocks of the age of sudburite are widespread and have frequently been mistaken for Keewatin. They are represented by the peridotite and augite lamprophyre of the Porcupine region, one hundred miles north of Sudbury, and by the lamprophyres and other rocks of Cobalt, ninety miles to the northeast of Sudbury. For economic purposes, at least, some age name should probably be applied to these basic rocks. Sudburian would be suitable had it not been used in another sense.

While Coleman and the authors are agreed on the age relations of the two great series of granites and gneisses, different nomenclatures are employed. The rocks that he calls "Granites Eruptive through the Keewatin," and to which he gives no distinctive age name, we class as Laurentian. In his classification Laurentian is applied to the granites and gneisses that we, following Lawson's nomenclature, class as Algoman.

The appellation Laurentian was first given to the rocks of the district bordering the Lower Ottawa River, and the older granites and gneisses here are different in age from the Algoman. The fact that the rocks now called Algoman have frequently been classed as Laurentian should not be given consideration. If the name Laurentian is to be retained, it should be applied to the oldest granites and gneisses. The following quotation shows that Logan did not intend that the name should be applied to granites that are intrusive into any part of his "Huronian." Further, it will be seen that, in the classic area of Lake Huron, Logan recognized both the Laurentian which, in his opinion, underlies all of his Huronian sediments, including that part of them now known as Timiskamian, and granites eruptive into the Huronian. Unfortunately later work has shown that much, at least, of what he considered to be Laurentian is really the intrusive granite which he called Huronian granite.

[1] *Ont. Bur. Mines*, XXIII, 215–17.

The intrusive granite occupies a considerable area on the coast of Lake Huron, south of Lake Pakokagaming. It there breaks through and disturbs the gneiss of the Laurentian series and forms a nucleus from which emanates a complexity of dykes, proceeding to considerable distances. As dykes of a similar character are met with intersecting the rocks of the Huronian series [Timiskamian], the nucleus in question is supposed to be of the Huronian age, as well as the greenstone dykes which are intersected by it.[1]

If Logan mistakenly applied the name Laurentian to his "Huronian granite" in certain areas, why should his mistake be perpetuated? Now that we know these granites and gneisses in some localities belong to what he called Huronian granite, why should we apply the name Laurentian to them instead of to the group that is much older, the Laurentian of our classification and the "Granites Eruptive through the Keewatin" of Coleman's?

There are certain objections to giving the names of systems or series to intrusives such as the Laurentian and Algoman. For this reason the authors prefer to inclose the names in parentheses in the table of classification, thus: (Laurentian intrusives) and (Algoman intrusives), or (Laurentian) and (Algoman). These intrusives occur in such great volume in the pre-Cambrian that it would seem well to retain distinctive age names for them. Age names are especially useful in economic work, our most important gold deposits, for example, being genetically connected with the Algoman.

DUAL SUBDIVISION

A dual subdivision of the pre-Cambrian, as shown in Table II, is employed by many authors. It is purely arbitrary, and is now known to be based on a misconception as to the relations of the rocks. It was believed, or assumed, that the greatest unconformity within the pre-Cambrian is that at the base of the "Lower Huronian," as the term is used by the U.S. Geological Survey. Such, however, has not proved to be the case. There is no proof that the unconformity at the base of the Timiskamian is of less magnitude than that at the base of the Animikean, of the authors' classification, or vice versa. According to Coleman, the various sedimentary series of the Timiskamian, his Sudbury series, where

[1] *Geology of Canada*, 1863, p. 58.

TABLE II

AGE CLASSIFICATIONS OF PRE-CAMBRIAN ROCKS OF ONTARIO PROPOSED BY VARIOUS AUTHORS

Miller and Knight*	Coleman†	Collins‡	Lawson§	*U.S. Geol. Survey Bull. 360*‖
KEWEENAWAN	KEWEENAWAN (Post Laurentian)	KEWEENAWAN (Huronian)	KEWEENAWAN (Nipigon) (Algonkian)	KEWEENAWAN (Algonkian)
Unconformity	*Unconformity*	*Unconformity*	*Unconformity*	*Unconformity*
ANIMIKEAN (with minor unconformities)	ANIMIKIE *Unconformity* UPPER HURONIAN *Small unconformity* LOWER HURONIAN (Post Laurentian)	WHITEWATER LORRAIN *Local unconformity* COBALT (Huronian)	ANIMIKIE (Algonkian)	UPPER HURONIAN *Unconformity* MIDDLE HURONIAN *Unconformity* LOWER HURONIAN (Algonkian)
Great unconformity	*Great unconformity*	*Great unconformity*	*Epparchean interval*	*Unconformity*
(ALGOMAN INTRUSIVES)	(LAURENTIAN, in eruptive contact with lower rocks)	Batholithic granite intrusives (Pre-Huronian)	ALGOMAN (granite-gneiss, batholithic in HURONIAN) (Archean)	
Intrusive contact		*Intrusive contact*	*Irruptive contact*	
TIMISKAMIAN	SUDBURY (Pre-Laurentian)	SUDBURY, TIMISKAMING, etc. (Pre-Huronian)	UPPER HURONIAN *Unconformity* LOWER HURONIAN (Archean)	
Great unconformity	*Great unconformity*	*Unconformity*	*Unconformity*	
(LAURENTIAN INTRUSIVES)	(Granites eruptive through the Keewatin) (Pre-Laurentian)	Granite intrusives (Pre-Huronian)	LAURENTIAN (granite-gneiss, batholithic in Ontarian) (Archean)	LAURENTIAN (Archean)
			Irruptive contact	
LOGANIAN: Grenville (*Sedimentary*); Keewatin (*Igneous*)	KEEWATIN, probably equivalent of Grenville (Pre-Laurentian)	Keewatin group (Pre-Huronian)	ONTARIAN: Keewatin; Couchiching (Archean)	KEEWATIN (Archean)

* *Ont. Bur. Mines*, XXII, Part II, Appendix.
† *Ibid.*, XXIII, Part I, p. 206.
‡ *Compte-Rendu, 12th Int. Geol. Congress*, p. 405.
§ *Ibid.*, p. 321.
‖ Pp. 42 and 43.

most fully developed, appear to have an approximate aggregate thickness of 29,000 feet.[1] Elsewhere these sediments are also known to have great thickness.

The term "Eparchean Interval," concerning which there has been so much discussion in the past, should now be discarded. The so-called Lower and Middle Huronian rocks of the classic area of Lake Huron lie above and not beneath it. There are now known to be two great "intervals" in the pre-Cambrian, that beneath our Animikean and that beneath our Timiskamian, and not merely one as has been assumed.

Moreover, a dual subdivision of the pre-Cambrian cannot be justified on the basis of differences in metamorphism or other characteristics of the rocks. Normally there is a gradual increase in degree of metamorphism from the youngest to the oldest. In the province of Ontario the Animikean rocks are only slightly metamorphosed or disturbed, while the Timiskamian are disturbed and frequently rendered schistose, and the Loganian are highly metamorphosed.

Sediments, Grenville, occur in great volume in the Loganian. Hence the "Archean" cannot be said to be essentially igneous, as assumed at one time. Moreover, ordinary stratigraphic methods, which have been cited as a test as to whether certain groups of rocks should be classed as Archean or otherwise, can be applied in studying the Grenville. This has been shown by the authors' work in southeastern Ontario.[2]

Briefly, it may be said that the discovery of the true relations of the Timiskamian destroys the argument for a dual classification of the pre-Cambrian.

COMMENTS ON TABLES I AND II

The name Keweenawan in the tables is employed in the sense in which it has been used by most writers on the pre-Cambrian of North America. Certain greenstones in the Lake Huron area were classed by Logan as intrusives of Huronian age. They have come to be known as the "Thessalon greenstones," after the name

[1] *Ont. Bur. Mines*, XXIII, 214.

[2] *Ibid.*, XXII, Part II, pp. 41 f.

of the near-by town, and during the last decade they have been frequently referred to in literature and classed as of Keewatin age. In the summer of 1914, however, the junior author was able to verify Logan's conclusion regarding their age, and to prove that they are in intrusive contact with the Animikean, as defined in Table I. Hence they are classed as Keweenawan.

The group name Animikean is explained in a preceding paragraph as well as in Table I. In addition to what has long been called the Animikie, it includes the usually flat-lying sediments of Lake Huron, which have been classed as Lower and Middle Huronian by various authors. There is an unconformity within these sediments but we do not think it is of the magnitude that it has been inferred to be. It is to be described in a forthcoming paper.[1] We look on this unconformity as being similar to those which have been observed in the Cobalt series. As already said, the flat-lying sediments of Lake Huron, the Ramsay Lake series of Sudbury, and the Cobalt series, all being of post-Algoman age and no discordance having been proved to exist between them and the Animikie, are classed by us with the latter rocks under the name Animikean. It may be added that the quartzites and jasper conglomerates of the upper part of the Lake Huron series resemble rather closely the upper part of the Cobalt series. As shown in Table II, Collins applies the local name Whitewater series to the sedimentary rocks of the Sudbury Nickel Basin. The name was given, however, by Nickles and Foerste in 1905 to a part of the Richmond.[2] Hence, it should not be employed for the Sudbury rocks. The name Fabre, which has been used by certain authors as synonymous with Sudbury or Timiskaming, should also be discarded, since the rocks to which the name was applied are merely part of the Cobalt series.[3]

The name Algoman was introduced by A. C. Lawson in 1913.[4] The authors, having found, in the areas examined by them, that granite and gneiss of post-Timiskamian and pre-Animikean age are of wide extent, had employed local names to designate these rocks. At Cobalt the granite was called Lorrain and in southeastern

[1] *Ont. Bur. Mines*, XXIV.

[2] *U.S. Geol. Survey, Professional Paper* 71, p. 172.

[3] *Ont. Bur. Mines*, XIX, Part II, p. 62.

[4] *Compte-Rendu, 12th Int. Geol. Congress*, pp. 359–61.

Ontario, Moira, while other writers had given the name Killarney to the granite that occurs along the north shore of Lake Huron. Algoman now being preferred, although not having priority, the other names may be discarded or used locally.

Basic rocks, of pre-Algoman and post-Timiskamian age, described in a preceding paragraph, are widespread, but no age name is given to them in the tables.

The age relations of the Timiskamian rocks have already been described, and reasons have been given for preferring the use of this name to the other that has been proposed for them.

On a preceding page reasons have been advanced for applying the name Laurentian to the pre-Timiskamian granites and gneisses and not to those of post-Timiskamian age.

The authors agree with Lawson that the Keewatin and the Grenville, or Couchiching, should be grouped together. Ontarian, however, should not be employed as the name of a pre-Cambrian group, since the New York State geologists have long used the term Ontaric (or Ontario) as synonymous with Siluric. Recognizing the objection to Lawson's use of the term, we have substituted for it the name Loganian, as shown in Table II.[1]

According to the views of the authors, the relations between the Keewatin and the Grenville are as follows: The Keewatin rocks represent, for the most part, submarine lava flows. On the surface of these flows are deposited the Grenville sediments. Moreover, it is believed that, while the major part of the Grenville is later than the major part of the Keewatin, a minor part of one group is contemporaneous with a minor part of the other. Hence the two groups, volcanic and sedimentary respectively, are placed in the authors' classification under one age term, the Loganian. Lawson's Couchiching, it seems to the authors, should be correlated with the base of the Grenville, and, since Grenville is the older term, we prefer to discard Couchiching or use it only locally.

That part of the Loganian known as the Grenville is found in much greater volume in southeastern Ontario and the adjacent part of Quebec than in the northern and northwestern parts of the

[1] *Ont. Bur. Mines*, XXII, Part II, Appendix.

province. This is apparently chiefly due to less erosion having taken place, especially prior to Timiskamian time, in the southeastern section than in the others. Over the northern and northwestern areas the Grenville was eroded until only comparatively small remnants in most localities were left. Later erosion, and intrusions, especially the Algoman, have also assisted in destroying the Grenville. However, the broader, more extensive areas of the series in the southeast can be connected, by tracing outliers from point to point, with the exposures in the north and northwest, where occur Timiskamian and Animikean rocks.

Coleman has described a comparatively large area of Grenville rocks, seven or eight miles southeast of the town of Sudbury, whose relations to the Timiskamian, his Sudbury series, he has determined.[1] The Grenville here consists of cyrstalline limestone, quartzite, and various schists and gneisses, while the Timiskamian contains quartzites, greywackes, and other sediments. The Grenville series is profoundly metamorphosed. The Timiskamian, on the other hand, while often schistose and resting in highly inclined positions, has suffered much less metamorphism than the Grenville. There can be no doubt that the two series near Sudbury are separated by a great discordance and that the Grenville is vastly older than the Timiskamian. Similar relationships are found in other localities in most of which the Grenville is represented by only very small outliers.

Near the eastern end of Lake Kipawa, Quebec, which lies not far distant from the foot of Lake Timiskaming, there is an area of Grenville, consisting of crystalline limestone and other sediments. These rocks, described by the senior author in 1901, have been much disturbed by an intrusion of granite, apparently of the same age as that of Lake Timiskaming, on the eroded surface of which lie the fragmental rocks of the Cobalt series, Animikean.[2]

It would thus seem that the authors are justified in correlating the rocks of southeastern Ontario with those to the north and northwest. They have no doubt as to the relations of the Grenville to the Keewatin which occurs in large volume in the southeastern part

[1] *Ont. Bur. Mines*, XXIII, 208–9.

[2] *Am. Geologist*, January, 1901; *Ont. Bur. Mines*, XIII, 102.

of the province as well as in the north and northwest. In the southeastern section there is also a series, the Hastings, that is believed to represent the Timiskamian of the north.[1]

METALLOGENETIC NOTES

During the last decade, owing to the great progress that has been made in the production of metals in Ontario, special facilities have been provided for the study of pre-Cambrian rocks. Our information has been much increased concerning the age relations not only of the rocks that represent various epochs of this great period but also of the ore deposits that are associated with them. Of no other part of the continent, or of the world, has the pre-Cambrian proved to be of greater economic interest. The province not only has the world's greatest deposits of nickel, among which have been developed mines that compare favorably in economic importance with those of any other metal found elsewhere, but the gold mines and the cobalt-silver areas are recognized as being among the greatest known.

From Table III it will be seen that there were at least four great metallogenetic epochs during the pre-Cambrian period in Ontario—Grenville, Algoman, Animikean, and Keweenawan. A fifth epoch of minor importance should probably be added to represent the ore bodies associated with the basic intrusives that preceded the intrusion of the Algoman granite and followed the deposition of the Timiskamian sediments. There is proof that many important ore deposits have been removed by erosion, and it seems not unlikely that the rocks of certain epochs, not now productive, contained deposits which have disappeared through the removal of vast thicknesses of material.

SEQUENCE OF INTRUSION AND METAL DEPOSITION

Table III brings out an interesting alternation of intrusion and sedimentation, and the importance of the igneous rocks in the formation of ore deposits. It will be seen that there are broadly five great epochs of igneous activity, basic and acid rocks alternating, viz.: (1) Keewatin, basic; (2) Laurentian, acidic; (3) pre-Algoman, basic; (4) Algoman, acidic; (5) Keweenawan, basic,

[1] *Ont. Bur. Mines*, XXII, Part II.

passing in places into a considerable volume of acidic varieties. The pre-Algoman basic rocks are of greater volume and wider extent than they are usually recognized to be, since they are frequently wrongly classed as Keewatin. These basic rocks are

TABLE III

PRE-CAMBRIAN EPOCHS OF ONTARIO AND THEIR METAL PRODUCTION

KEWEENAWAN	Epoch, following basic intrusions, of (*a*) silver, cobalt, nickel, and arsenic at Cobalt and elsewhere, (*b*) nickel and copper at Sudbury, and copper elsewhere. Certain gold deposits, not now productive, appear to belong to this epoch.
ANIMIKEAN	Epoch of deposition of "iron formation" as a chemical precipitate.
(ALGOMAN)	Epoch, following granite intrusions, of gold at Porcupine and at many other localities, and of auriferous mispickel. Deposits of galena, zinc blende, fluorite, and other minerals also appear to have been derived from the granites, but some of them were not formed till post pre-Cambrian time. Preceding the intrusion of the Algoman granites, basic intrusives, that appear to be of post-Timiskamian age, gave rise to nickel and titaniferous and non-titaniferous magnetite deposits and chromite.
TIMISKAMIAN	Epoch of minor deposition of "iron formation" as a chemical precipitate.
(LAURENTIAN)	Granite intrusions probably gave rise to ore deposits which have been removed by excessive erosion as is known to be the case with deposits of later origin.
LOGANIAN	
Grenville	Epoch of deposition of extensive "iron formation" as a chemical precipitate among other sediments.
Keewatin	Composed largely of basic volcanic rocks.

represented by the sudburite of the Sudbury area, by the lamprophyres of Cobalt and elsewhere, and apparently by the basic rocks of the townships of Dundonald, Reaume, and others where associated with them are nickeliferous pyrrhotite and chromite.

Owing to erosion, the sequence of metal deposition shown in Table III is doubtless incomplete.[1] Iron formation occurs in three

[1] Two or three hundred feet more of erosion would have left comparatively little, for example, of the Cobalt silver deposits, of which, it would seem, more has been eroded than has been mined, or even of the great Mesabi iron deposits of Minnesota.

epochs, the Loganian, Animikean, and Timiskamian, but is of economic importance only in the former two. Certain deposits of titaniferous and non-titaniferous magnetites, not now being worked, are associated with basic intrusives that appear to be of pre-Algoman age. Arsenic occurs in two epochs and has been produced in economic quantities from the rocks of both. In so far as is known, gold occurs in economic quantity only in the Algoman, although small quantities are obtained in refining the copper-nickel ores, and certain auriferous quartz deposits, not now productive, appear to be genetically connected with Keweenawan intrusives. Nickel, as has been shown in the preceding table, was deposited in economic quantities in two epochs. Cobalt, silver, and copper are produced only from deposits of Keweenawan age. Platinum, palladium, mercury, and other metals are found in small quantities with Keweenawan ores. Zinc and lead have been mined in the province, but the age relations of some of the deposits are in doubt.

RELATIVE ECONOMIC IMPORTANCE OF VARIOUS EPOCHS

In Ontario in 1913, the metal production from ore deposits of various pre-Cambrian epochs was as follows: Keweenawan (silver, copper, nickel, cobalt, arsenic), $36,559,688; Algoman (gold), $4,543,690; Keewatin-Grenville (iron and iron ore), $1,195,150. A comparatively small quantity of the nickel and copper credited to the Keweenawan should be assigned to deposits that are associated with basic eruptives of pre-Algoman, and probably post-Timiskamian age, but the value is not definitely known.

While at present in Ontario there is no production from deposits of Animikean or Timiskamian age, millions of tons of iron ore are mined from deposits of these epochs in the state of Michigan.

It is to be understood that the ages given for the deposits do not refer to secondary concentration, as, for instance, in the case of iron ores, but to the epoch in which the metals were first deposited.

In a paper entitled "Metallogenetic Epochs in the Pre-Cambrian of Ontario," presented before the Royal Society of Canada, May, 1915, the authors discuss more fully the age and genetic relations of the ore deposits of the province.

METAMORPHIC STUDIES[1]

CONVERGENCE TO MINERAL TYPE IN DYNAMIC METAMORPHISM

C. K. LEITH AND W. J. MEAD
University of Wisconsin

The thesis of this paper is that the formation of slates, schists, and some gneisses, by rock flowage, requires both mineralogical and chemical changes, and that there is convergence, both chemically and mineralogically, toward a comparatively few platy or columnar minerals, tending to give these rocks their characteristic lamellar structure. If such convergence can be demonstrated, it may be used as a guiding principle in the study and interpretation of this phase of metamorphism. In this paper it is proposed to discuss anamorphism from this point of view.

Mineral changes in anamorphism by rock flowage.—It is generally recognized, and need not here be demonstrated, that anamorphism by rock flowage tends to produce platy and columnar minerals, like mica, chlorite, hornblende; that these increase at the expense of other minerals during the process, and that in the resulting slates, schists, or gneisses, they are the characteristic minerals which determine the lamination and cleavage of the rock and give the rock its name. Quartz and feldspar are also important minerals in the slates, schists, and gneisses, but these minerals are less important than the first-named group in producing the essential characteristics of the slates, schists, and gneisses, and they tend to diminish relatively in quantity in proportion as platy and columnar minerals increase. Mica, chlorite, hornblende, feldspar, and quartz make up all but an insignificant part of the mass of schists, slates, and gneisses. There are of course other minerals developed, such as garnet, staurolite, chloritoid, sillimanite, andalusite, etc., which in certain rocks may be conspicuous and

[1] See also C. K. Leith, "The Metamorphic Cycle," *Jour. Geol.*, XV (1907), 303–13; C. K. Leith and W. J. Mead, "Metamorphic Studies," *ibid.*, XX (1912), 353–61; C. K. Leith and W. J. Mead, *Textbook of Metamorphism* (in press, Henry Holt & Co.).

distinctive, and therefore are used in naming the rock, but in abundance they must be regarded as distinctly minor and accessory constituents as compared to the principal constituents before named.

In the progressive changes from a mud or clay to a shale and in turn to a slate or schist, there is an increase in the percentage by weight of mica and chlorite with relative decrease of other constituents. Muscovite or sericite makes up from a third to a half of mica slates, according to Dale,[1] and in a phyllite may be in even larger proportion, whereas in the original rock the percentage was but a small fraction of this amount. There is corresponding decrease in kaolin, feldspar, and certain ferromagnesian minerals.

Where a sandstone or quartzite becomes schistose there is an increase of mica, with corresponding decrease of other constituents. Certain specific instances of development of sericite schists in shear zones crossing the bedding of a quartzite have shown elimination of the greater part of the quartz of the original rock, due to solution, probably aided greatly by minute granulation.

A limestone or a marble may become schistose purely by process of granulation, which involves no essential development of new minerals. But more often there is a striking development of amphibole and other silicates with a corresponding diminution in calcite. Silicated marbles, resulting from metamorphism, are too well known to need further description.

A granite, by metamorphism during rock flowage, may become a mica schist or mica gneiss. Mica is increased at the expense of the feldspar and some of the ferromagnesian minerals.

A basic igneous rock, by dynamic metamorphism, may become a chlorite or hornblende schist or gneiss, the increase of chlorite or hornblende being counterbalanced by decrease in feldspar and pyroxene.

The average igneous rock, according to Clarke,[2] has about 60 per cent feldspar, 28 per cent ferromagnesian and accessory

[1] T. Nelson Dale, "Slates of the United States," *Bull. 586, U.S. Geol. Survey*, 1914, p. 20.

[2] F. W. Clarke, "The Data of Geochemistry," *Bull. 491* (2d ed.), *U.S. Geol. Survey*, 1911, p. 398.

minerals, and 12 per cent quartz. The schists or gneisses developed from these igneous rocks have a considerably smaller proportion of feldspars. The ferromagnesian minerals, instead of consisting dominantly of augite and biotite, with some muscovite, are now largely hornblende and muscovite, with subordinate quantities of biotite.

Whether the parent rock is igneous or sedimentary, or whatever its mineral content, the resulting schists and gneisses are characterized by hornblende, chlorite, and mica, which are developed to such an extent that the very nature of the original rock is often lost. If the mineralogical change were not extensive, the problem of origin of schists and gneisses would not be nearly so difficult as it is. The very existence of the problem testifies to the great mineralogical changes which have occurred. A sericite schist, for instance, may result from dynamic anamorphism of a slate, an igneous rock, or a quartzite. A hornblende schist may result from the anamorphism of a limestone or marble or may develop from a basic igneous rock, a graywacke or other basic sediment, or a slate.

A few distinctive minerals, such as mica, chlorite, and hornblende, are the characteristic resulting products of anamorphism by rock flowage of a considerable variety of parent rocks. In this sense, then, there is a convergence toward a certain mineralogic type.

Chemical changes during anamorphism by rock flowage.—When the chemical changes in anamorphism by rock flowage are considered, there is less general acceptance of the fact that actual changes in composition take place and that these changes are in the direction of producing the composition of the characteristic minerals in the end-products. Probably it is the general view that the conditions of rock flowage and anamorphism are not usually favorable to extensive transfers of materials involved in change of composition. It is often true that there are no important changes in percentages of chemical constituents during the process of rock flowage and anamorphism, the mineralogical change having been accomplished through recrystallization of substances present. This is especially true when the original rocks are well adapted, in

their composition, like shales, to the production of the necessary schist-making minerals. But even in these cases the elimination of water, carbon dioxide, and oxygen is recognized. We think it can be likewise inferred, in cases where the composition of the parent rock differs widely from the composition of the hornblende, mica, or chlorite, that important chemical changes take place, principally by the elimination of the substances present in excess of these requirements, but possibly also in some cases by addition of substances from without, and that there is therefore a chemical as well as mineralogical convergence toward mineral types.

Illustrative of such changes is the diminution of carbon dioxide, and perhaps lime, when a marble becomes silicated. In extreme cases an amphibolite has been described as the end-result of the alteration of marble. This obviously means a considerable change in chemical composition. For the purposes of our argument it is immaterial whether this change consists dominantly of elimination or of substitution of constituents from without along igneous contacts. Rock flowage and anamorphism are often accomplished under conditions which make it impossible to determine the relative importance of the purely mechanical and of the igneous influence respectively in their production. The point we would emphasize is that the characteristic product like amphibolite or silicated marble resulting from rock flowage or anamorphism differs distinctly in composition from the primary limestones or marble.

The development of talc schist from the anamorphism of a dolomite indicates an important change of composition, like that in the Menominee district of Michigan.[1]

A quartzite often becomes sheared and transformed into a sericite schist. Where shearing follows impure phases of the quartzite parallel to the bedding, it is difficult to prove any change in composition, but where the sericite schist develops in shear zones, crossing massive beds of quartzite, and samples can be collected showing complete gradation of the massive quartzite into the sericite schist, there is conclusive evidence of the elimination of quartz. The authors have carefully sampled two good cases of

[1] W. S. Bayley, "Menominee Iron-bearing District of Michigan," *Mon. 46, U.S. Geol. Survey*, 1904.

this kind in the Marquette district of Michigan. Another case is worked out in similar fashion by J. H. Warner on the Waterloo quartzite of Wisconsin, where shear zones cross the bedding. Analyses of these rocks,[1] show that the larger part of the free quartz has been eliminated, presumably through solution aided by granulation.

Where shales are traced into slates or schists the change in composition is less obvious, owing to the fact that the shale originally possesses pretty nearly the composition required by the end-products, but even here, important changes in composition are noted, like the elimination of CO_2, water, and oxygen, and, in some cases, the increase of potash.

A greenstone in the Marquette district of Michigan has been traced inch by inch into a sericite-chlorite schist and sampled on a large scale, the resulting analyses showing elimination of silica, an increase of alumina and ferric oxide, potash, and a considerable decrease in lime. Similar changes are described and analyzed by George H. Williams.[2]

It is not easy to find in the field satisfactory gradations from massive to schistose rocks where one can be certain that the mass was throughout of uniform composition. It is still more rare that these gradations have been thoroughly sampled so that the analyses furnish an adequate basis for comparison. It is significant, however, that where this has been done—and we have searched the literature carefully—important changes are to be noted.

Fortunately we are not obliged in our conclusion to rely entirely on the few well-sampled gradations from primary to schistose rock. A study of the actual compositions of the principal groups of schists brings out the fact that these vary in certain essential respects from those of the primary rocks from which they are supposed to have been derived. In another discussion[3] of the use of chemical criteria in the identification of schists and gneisses,

[1] C. K. Leith and W. J. Mead, *Textbook of Metamorphism* (in press, Henry Holt & Co.

[2] G. H. Williams, "The Greenstone Schist Areas of the Menominee and Marquette Regions of Michigan; A Contribution to the Subject of Dynamic Metamorphism in Eruptive Rocks," *Bull. 62, U.S. Geol. Survey*, 1890.

[3] *Textbook of Metamorphism*, cited above.

analyses of common schists have been platted graphically in order that they may be compared with both known and possible parent rocks. An examination of these plates brings out the fact that the composition of the schist tends to approach the distinctive chemical characteristics of the dominant platy or columnar mineral in the schist. This is especially well shown in the sericite schist, the composition of which lies between that of the primary rock and that of the mineral sericite. It is indicated, not only by the position of the analyses on the diagram, but by the shapes of the flags showing the relative amounts of constituents. If we were to include in these plates only those schists in which the processes of anamorphism and rock flowage have gone to an extreme, the tendency would be still more obvious, because rocks are included in these diagrams, described as hornblende, chlorite, or mica schist, which have but a small proportion of these minerals.

Our inference from the available facts is that, while recrystallization of substances present has of course played an important part in the production of schists, for some rocks important changes in composition have also occurred; that these changes in composition have been toward the composition of the characteristic end-products—mica, hornblende, or chlorite; that these changes are known both in sedimentary and in igneous rocks, of both acid and basic composition, and that the changes have been sufficiently important to make it impossible, along with other reasons, to use chemical composition as a conclusive criterion for the identification of origin of schists and gneisses.

Significance of convergence.—If this idea of convergence be correct, our attention is directed to the physical and chemical characteristics of a few minerals like mica, chlorite, and hornblende as important factors in anamorphism by rock flowage. Obviously they are adapted to the conditions of rock flowage; otherwise they would not develop at the expense of other minerals. It is not so clear whether they are adapted by their crystal habits, by their cleavages, by their composition, or by a combination of these characters. The fact that they are always arranged according to their dimensions, their greatest and least mean being respectively parallel, and the fact that their dimensions in the schist are clearly those

determined by their habit of crystal growth, rather than by any growth or breaking giving other shapes, direct our attention to the crystal habit of these minerals as essential reasons for their development. Whether processes of rock flowage have been weak or intense, the resulting minerals maintain their habit and dimensional characteristics.

If convergence toward certain characteristic minerals is established in rock flowage, the question naturally arises whether these end-products can be regarded purely as results of the great variety of processes in anamorphism by rock flowage, or whether the individual characters of the resulting minerals have exerted a certain directive and controlling influence in converging the various lines of anamorphism and rock flowage toward themselves, and more particularly whether the crystal habit of these minerals has exerted this influence. From this point of view it seems to be something more than a coincidence that, under such a variety of conditions and with such variety of available materials, that which we call crystallizing force has been able to exert itself to the extent of causing important mineralogical and chemical changes toward a limited number of mineral forms. It has drawn to itself the materials needed, eliminated those not needed, and has developed crystals of uniform habit. Under given environment it has had the capacity to organize the substances in a fashion best adapted to environment in much the same way that organisms have been supposed to adapt themselves to environment. The problem before us may be similar to the biologic question whether organisms are distinctly the results of physical and chemical environment or whether that mysterious force we call life on occasion rises superior to environment and to some extent modifies and controls external conditions. It is sometimes said that man is the multiplier and environment the multiplicand in the product determining history. The attempt to apply the same reasoning to the development of certain characteristic minerals in schists suggests the crystallizing power of these crystal individuals as the multiplier and environment as the multiplicand in the product representing rock flowage.

It is of interest also to note that the convergence here argued is toward a group mineralogically and chemically different from

primary igneous rocks, from which all metamorphism presumably starts, and is essentially a by-product of the metamorphic cycle. The difference between schists, gneisses, and slates, on the one hand, and igneous rocks on the other, represents a gap which has not been closed by the metamorphic cycle. The schists, gneisses, and slates represent types which are clearly nearer the composition of the original igneous rock than many of the rocks, particularly the sediments, which have been anamorphosed and recrystallized and have undergone rock flowage.

This convergence toward igneous rock composition often reaches a point where chemical criteria are not sufficient to determine whether or not the primary rock was igneous or sedimentary, the resulting composition being so nearly that of an igneous rock. If, along igneous contacts, a considerable amount of material has been completely fused, the anamorphic product may take on the character of an igneous rock and in such places the cycle is closed. But just as sandstones or limestones may be regarded as products of the cycle, some of which never go back to their primary condition of igneous rocks, so the schists and gneisses are by-products, which do not go back to the condition of igneous rocks under ordinary conditions of anamorphism. Whether the cycle in its larger aspects is completely closed, so far as the great mass of products is concerned, is a very doubtful question which has been discussed in a previous paper.[1]

[1] *Jour. Geol.*, XX (1912), 353–61.

THE AGE OF THE CRETACEOUS FLORA OF SOUTHERN NEW YORK AND NEW ENGLAND

EDWARD W. BERRY
Johns Hopkins University

The age of the plant-containing Upper Cretaceous which outcrops, or is found in morainal deposits, on Staten Island, along the north shore of Long Island, and on Block Island and Martha's Vineyard has never been exactly determined, although their obvious general relations may be indicated by the fact that as early as 1838 Mather[1] suggested their equivalency with the New Jersey beds around Raritan Bay.

Only one or two points in the history of their study need be mentioned. Newberry considered them the equivalent of the Amboy clays which as then developed paleobotanically were almost entirely Raritan. Ward[2] named them the Island series and considered them uppermost Potomac but post-Raritan, the latter being erroneously regarded as of late Lower Cretaceous age.[3] White,[4] who was the first to prove the existence of Upper Cretaceous on Martha's Vineyard is quoted by Veatch (1906) as holding that the plant beds on that island are about equivalent to those at Cliffwood, New Jersey, an undoubtedly correct interpretation.

It was not until the Magothy formation was delimited from the underlying Raritan formation and the overlying Matawan formation by Clark[5] in 1904 and its flora described by the writer[6] that adequate paleobotanical data were available for exact comparisons with the more or less isolated and disturbed outcrops to the eastward.

[1] W. W. Mather, *Rept. First Dist. N.Y.* (1838), pp. 136–37.

[2] Lester F. Ward, *Fifteenth Ann. Rept. U.S. Geol. Surv.* (1895), p. 335.

[3] It is not worth while to consider the claim of O. C. Marsh that these beds represent Jurassic sediments.

[4] D. White, *Am. Jour. Sci.* (III), XXXIX (1890), 93–101.

[5] W. B. Clark, *Am. Jour. Sci.* (IV), XVIII (1904), 435–40.

[6] E. W. Berry, *Ann. Rept. State Geol. N.J. for 1905*, pp. 135–56.

In the last few years the geology of Long Island has been studied by Veatch,[1] Fuller,[2] and others, and the southward extensions of the Raritan and Magothy floras across New Jersey and in Delaware and Maryland have been investigated by the writer.[3] From the strike of the Cretaceous beds across Long Island as determined by the authors above mentioned; by a study of their lithology and genesis; and by an analysis of the insular floras, for a knowledge of which we are indebted almost entirely to the long-continued labors of Dr. Arthur Hollick,[4] it is now possible to determine with certainty the age of a number of the localities where Cretaceous plants have been found and to show with a fair degree of probability the age of the original deposits from which the more outlying morainal-materials-carrying plants have been derived.

Without burdening the reader with the steps in this analysis, the conclusions at which the writer has arrived will be given, and a list of the Raritan and Magothy floras will be appended, so that the following statements can be verified by anyone that cares to take the trouble to do so.

The beds on Staten Island offer little difficulty, since they are practically continuous with those of New Jersey; in fact Hollick has indicated in several publications that the celebrated Kreischerville outcrops are of Raritan age. From clays in place plants have been collected at Green Ridge and around Kreischerville. From morainal material Upper Cretaceous plants are recorded from Tottenville, Richmond Valley, Princess Bay, and Arrochar. These also are probably all of Raritan age.

Along the north shore of Long Island fossil plants have been collected from clays in place at Glen Cove, Cold Spring, and Northport. From the geographical position of these outcrops, their distance above bedrock, and as is conclusively shown by

[1] A. C. Veatch, *Professional Paper No. 44, U.S. Geol. Surv.*, 1906.

[2] M. L. Fuller, *Professional Paper No. 82, U.S. Geol. Surv.*, 1914.

[3] E. W. Berry, Contributions to the Mesozoic Flora of the Atlantic Coastal Plains: I, *Bull. Torrey Bot. Club*, XXXIII (1906), 163–82, pls. 7–9; IV, *Ibid.*, XXXVII (1910), 19–29, pl. 8; VII, *Ibid.*, XXXVIII (1911), 399–424, pls. 18, 19; X, *Ibid.*, XLI (1914), 295–300.

[4] Nearly all the literature is summarized by him in *Mon. U.S. Geol. Surv.* (1906). L, since which date only a few minor papers have been published.

their extensive flora, they are unquestionably of Magothy age. Fossil plants have been found in morainal materials at a large number of localities on Long Island. These are Brooklyn, Elm Point (Great Neck), Mott Point (Manhasset Neck), Glen Cove, Sea Cliff, Dosoris Island, Lloyd Neck, Eaton's Neck, Roslyn, Oak Neck, and Montauk Point.

While it is quite possible that some of these materials may have been derived from Raritan outcrops once present to the northward, the flora does not indicate Raritan affinities. Of the 100 species listed from Long Island in *Monograph 50* (*op. cit.*), only 33 have been found in the New Jersey Raritan, which is about the same proportion that survives from the Raritan into the overlying Magothy formation in the New Jersey area. There is then no paleobotanical evidence of the existence of the Raritan east of Brooklyn.

The probable genesis of the Raritan has an important bearing on this question. The Raritan formation in the area of its type development (i.e., around Raritan Bay, New Jersey, the so-called Amboy district) consists of a lower, middle, and upper horizon with thick, argillaceous beds, separated by well-defined sand beds from 35 to 50 feet in thickness. The Raritan fire and potter's clay at the base is about 35 feet thick. The middle or Woodbridge clays range from 30 to 60 feet in thickness, while the upper clays (South Amboy fireclay and stoneware clay) are about 50 feet in thickness. These all carry fossil plants. In discussing this flora the writer has demonstrated[1] that it shows a remarkable cleavage into an older flora (Lower and Middle Raritan) and a younger flora (Upper Raritan), from the latter of which a large number of the forms common to the Magothy take their origin. In tracing the Raritan southwestward across New Jersey, Delaware, and Maryland to the Potomac River valley it has been found impossible to recognize the well-marked divisions described in the Amboy district. The massive clays of the latter are replaced within a dozen miles by prevailingly arenaceous deposits, and with the exception of certain well records, e.g., Fort Dupont, Delaware,

[1] E. W. Berry, "The Flora of the Raritan Formation," *Bull. 3, Geol. Surv. of New Jersey*, 1911.

which are open to various interpretations, the formation is everywhere much thinner. This is capable of more than one explanation, but from a consideration of all the facts it seems probable that at least the older Raritan, that is to say the Lower and Middle Raritan of the Amboy district from the base to the top of the Woodbridge clays, the upper surface of which shows considerable erosion, is a purely local deposit continental or estuarine in character, and that the southwesterly extension of the Raritan represents the Upper Raritan. In endeavoring to trace the Raritan eastward beyond Staten Island one searches in vain in the very numerous well records (Veatch listed over 900 in 1906) for the representatives of the Raritan, Woodbridge, and Amboy clays, the basal beds of the coastal plain in the eastern area being prevailingly sandy with irregular clay lenses of no great extent. This together with the paleobotanical evidence leads to the conclusion that the Lower and Middle Raritan were never present east of Brooklyn, and that while the Upper Raritan may have extended eastward as it did to to the southwestward there is at present no evidence of such an extension. If the Long Island Cretaceous were Upper Raritan, the described floras are extensive enough to determine this point.

Obviously, if the Raritan failed to extend along the north shore of Long Island it was never represented on Martha's Vineyard, Block Island, or the Elizabeth Islands, and this is strikingly confirmed by the lithologic character of the Upper Cretaceous in the latter region and by the extensive flora, as has been recognized to a more or less degree by White, Ward, and Hollick, who have studied this flora. Of the 126 recorded species from Martha's Vineyard and Block Island only 36 are found in the Raritan. The number common to the Magothy is but 37, but these include a large number of forms that are distinctive horizon markers and range to higher levels in our southern states.

According to the age determinations as outlined above, the Raritan and Magothy floras are segregated in the following lists. These show that the Raritan flora comprises 224 and the Magothy flora 289 species (so called); 61 per cent of the Raritan flora does not extend into the Magothy and 70 per cent of the Magothy flora does not occur in the Raritan. A mere statistical method does

not, however, sufficiently emphasize their contrasts. The Raritan contains a number of types that survived from the Lower Cretaceous, while the Magothy introduces many modern types in genera, among which the following may be mentioned:

Amelanchier	Doryanthites	Lycopodium	Paliurus	Planera
Araucaria	Elaeodendron	Marsilea	Panax	Rhamnus
Bumelia	Guatteria	Nectandra	Periploca	Rhus
Coccolobites	Gyminda	Nelumbo	Persea	Sabalites
Crataegus	Hedera	Ocotea	Picea	Viburnum
Dalbergia	Illicium	Onoclea	Pistia	Zizyphus

Only three of these genera are sparingly represented in the Raritan. It would hardly be worth while to follow the analysis farther in the present connection, as sufficient facts have already been given to establish the probability of the questions considered. Both Veatch and Fuller (*op. cit.*) consider that some of the north-shore outcrops represent the Raritan. Veatch, in discussing the underground waters of Long Island in 1906 (*op. cit.*) differentiated a horizon, the Lloyd sand, whose top is from 150 to 200 feet above bedrock. This sand, which may or may not be a continuous stratum, he believes he has identified in a considerable number of wells along both the north and south shores of Long Island and also in various records of wells in eastern New Jersey. He places it in the Raritan, but if it is really a continuous bed at the same stratigraphic level it probably represents the so-called laminated sands[1] formerly considered a part of the Raritan but shown by the writer to be lower Magothy[2].

Here follows lists of the plants identified from the Raritan and Magothy formations throughout their extent, which in the case of the latter is from Martha's Vineyard to the Potomac River valley, a distance along the strike of something like 450 miles (750 kilometers).

List of Plants Recorded from the Raritan Formation

Acer amboyense Newberry	Andromeda Cookii Berry
Acer minutum Hollick	Andromeda novae-caesareae Hollick
Acerates amboyense Berry	Andromeda Parlatorii Heer
Andromeda grandifolia Berry	Andromeda tenuinervis Lesquereux

[1] *Final Rept. State Geologist, N.J.*, VI (1904), 168.

[2] *Ann. Rept. State Geol. N.J., for 1905*, p. 136.

Androvettia statenensis Hollick and Jeffrey
Anomaspis hispida Hollick and Jeffrey
Anomaspis tuberculata Hollick and Jeffrey
Aralia formosa Heer
Aralia groenlandica Heer
Aralia Newberryi Berry
Aralia patens Hollick
Aralia quinquepartita Lesquereux
Aralia rotundiloba Newberry
Aralia washingtoniana Berry
Aralia Wellingtoniana Lesquereux
Araliopsis breviloba Berry
Araliopsis cretacea (Newberry) Berry
Araliopsis cretacea dentata (Lesquereux) Berry
Araliopsis salisbureaefolia (Lesquereux) Berry
Araucariopitys americana Jeffrey
Araucarioxylon noveboracense Hollick and Jeffrey
Aspidiophyllum trilobatum Lesquereux
Asplenium Dicksonianum Heer
Asplenium Foersteri Debey and Ettingshausen
Asplenium jerseyensis Berry
Asplenium raritanensis Berry
Baiera incurvata Heer
Bauhinia cretacea Newberry
Bauhinia gigantea Newberry
Brachyoxylon notabile Hollick and Jeffrey
Brachyphyllum macrocarpum Newberry
Caesalpinia Cookiana Hollick
Caesalpinia raritanensis Berry
Calycites diospyriformis Newberry
Calycites parvus Newberry
Carpolithus euomymoides Hollick
Carpolithus floribundus Newberry
Carpolithus hirsutus Newberry
Carpolithus ovaeformis Newberry
Carpolithus pruniformis Newberry
Carpolithus vaccinioides Hollick
Carpolithus woodbridgensis Newberry
Celastrus arctica Heer
Celastrophyllum Brittonianum Hollick
Celastrophyllum crenatum Heer
Celastrophyllum cretaceum Lesquereux
Celastrophyllum decurrens Lesquereux
Celastrophyllum grandifolium Newberry
Celastrophyllum minus Hollick
Celastrophyllum Newberryanum Hollick
Celastrophyllum spatulatum Newberry
Celastrophyllum undulatum Newberry
Chondrites flexuosus Newberry
Chondrophyllum obovatum Newberry
Chondrophyllum orbiculatum Heer
Chondrophyllum reticulatum Hollick
Cinnamomum Newberryi Berry
Cissites formosus Heer
Cissites Newberryi Berry
Citrophyllum aligerum (Lesquereux) Berry
Cladophlebis socialis (Heer) Berry
Colutea primordialis Heer
Comptonia microphylla (Heer) Berry
Cordia apiculata (Newberry) Berry
Cornophyllum vetustum Newberry
Cycadinocarpus circularis Newberry
Cyparissidium gracile Heer?
Czekanowskia capillaris Newberry
Dactyolepis cryptomerioides Hollick and Jeffrey
Dammara borealis Heer
Dammara minor Hollick
Dalbergia apiculata Newberry
Dalbergia hyperborea Heer?
Dewalquea groenlandica Heer
Dewalquea insignis Hosius and v.d. Marck
Dewalquea trifoliata Newberry
Dicksonia groenlandica Heer
Diospyros apiculata Lesquereux?
Diospyros primaeva Heer
Diospyros amboyensis Berry
Diospyros vera Berry
Eucalyptus angusta Velenovsky
Eucalyptus attenuata Newberry
Eucalyptus Geinitzi Heer
Eucalpytus linearifolia Berry
Eucalyptus parvifolia Newberry
Eugeinitzia proxima Hollick and Jeffrey
Ficus daphnogenoides (Heer) Berry
Ficus Krausiana Heer
Ficus myricoides Hollick

Ficus ovatifolia Berry
Ficus Woolsoni Newberry
Fontainea grandifolia Newberry
Frenelopsis Hoheneggeri (Ett.) Schenk
Geinitzia formosa Heer
Geinitzia Reichenbachi Hollick and Jeffrey
Gleichenia Giesekiana Heer
Gleichenia micromera Heer
Gleichenia Zippei Heer
Hedera obliqua Newberry
Hedera primordialis Saporta
Hymenaea dakotana Lesquereux
Ilex amboyensis Berry
Ilex elongata Newberry
Juglans arctica Heer
Juglans crassipes Heer
Juniperus hypnoides Heer
Kalmia Brittoniana Hollick
Laurophyllum angustifolium Newberry
Laurophyllum elegans Hollick
Laurophyllum lancealatum Newberry
Laurophyllum minus Newberry
Laurophyllum nervillosum Hollick
Laurus nebrascensis Hollick
Laurus Hollae Heer?
Laurus plutonia Heer
Leguminosites atanensis Heer
Leguminosites coronilloides Heer
Leguminosites omphalobioides Lesquereux
Leguminosites raritanensis Berry
Liriodendron oblongifolium Newberry
Liriodendron primaevum Newberry
Liriodendron quercifolium Newberry
Liriodendropsis angustifolia Newberry
Liriodendropsis retusa (Heer) Newberry
Liriodendropsis simplex Newberry
Magnolia alternans Heer
Magnolia Hollicki Berry
Magnolia Isbergiana Heer
Magnolia Boulayana Lesquereux
Magnolia Lacoeana Lesquereux
Magnolia longipes Hollick
Magnolia Newberryi Berry
Magnolia speciosa Heer
Magnolia woodbridgensis Hollick
Majanthemophyllum pusillum Heer
Menispermites borealis Heer
Menispermites Wardianus Hollick
Microzamia gibba (Reuss) Corda
Moriconia cyclotoxon Debey and Ettingshausen
Myrica acuta Hollick
Myrica cinnamomifolia Newberry
Myrica Davisii Hollick
Myrica emarginata Heer
Myrica fenestrata Newberry
Myrica Hollicki Ward
Myrica Newberryana Hollick
Myrica raritanensis Hollick
Myrsine borealis Heer
Myrsine Gaudini (Lesquereux) Berry
Myrsine oblongata Hollick
Newberryana rigida (Newberry) Berry
Paliurus affinis Heer?
Passiflora antiqua Newberry
Phegopteris Grothiana Heer
Phaseolites elegans Hollick
Phyllites poinsettioides Hollick
Phyllites trapaformis Berry
Pinus granulata (Heer) Stopes
Pinus quinquefolia Hollick and Jeffrey
Pinus raritanensis Berry
Pinus tetraphylla Jeffrey
Pinus triphylla Hollick and Jeffrey
Pistacia aquehongensis Hollick
Pitoxylon statenense Hollick and Jeffrey
Planera Knowltoniana Hollick
Platanus aquehongensis Hollick
Platanus Heerii Lesquereux
Persoonia Lesquereuxii Knowlton
Persoonia spatulata Hollick
Phaseolites manhassettensis Hollick
Pityoidelepsis statensis Hollick and Jeffrey
Podozamites acuminatus Hollick
Podozamites Knowltoni Berry
Podozamites lanceolatus (L. and H.) F. Braun
Podozamites marginatus Heer
Populus harkeriana Lesquereux
Populus orbicularis (Newberry) Berry
Prepinus statenensis Jeffrey
Protodammara speciosa Hollick and Jeffrey

Protophyllocladus subintegrifolius (Lesq.) Berry
Protophyllum multinerve Lesquereux
Prunus ? acutifolia Newberry
Pseudogeinitzia sequoiiformis Hollick and Jeffrey
Pterospermites modestus Lesquereux
Pterospermites obovatus (Newberry) Berry
Quercus ? novae-caesareae Hollick?
Quercus raritanensis Berry
Raritania gracilis (Newberry) Hollick and Jeffrey
Rhamnites minor Hollick
Salix flexuosa Newberry
Salix inaequalis Newberry
Salix Lesquereuxii Berry
Salix Newberryana Hollick
Salix pseudo-Hayei Berry
Salix raritanensis Berry
Sapindus Morrisoni Heer
Sassafras acutilobum Lesquereux
Sassafras hastatum Newberry
Sassafras progenitor Hollick
? Sequoia concinna Heer
Sequoia heterophylla Velenovsky
Sequoia Reichenbachi (Geinitz) Heer
Smilax raritanensis Berry
Sphaerites raritanensis Berry
Sphenaspis statenensis Hollick and Jeffrey
Strobilites Davisii Hollick and Jeffrey
Strobilites microsporophorus Hollick and Jeffrey
Tricalycites major Hollick
Tricalycites papyraceus Newberry
Tricarpellites striatus Newberry
Thuya cretacea (Heer) Newberry
Thuyites Meriana Heer
Viburnum integrifolium Newberry
Widdringtonites Reichii (Ettingshausen) Heer
Widdringtonites subtilis Heer
Williamsonia problematica (Newberry) Ward
Williamsonia Reesii Hollick
Williamsonia Smockii Newberry

List of Plants Recorded from the Magothy Formation

Acer paucidentatum Hollick
Amelanchier Whitei Hollick
Andromeda Cookii Berry
Andromeda grandifolia Berry
Andromeda novae-caesareae Hollick
Andromeda Parlatorii Heer
Aralia Brittoniana Berry
Aralia coriacea Velenovsky
Aralia Towneri Lesquereux
Aralia groenlandica Heer
Aralia mattewanensis Berry
Aralia nassauensis Hollick
Aralia Newberryi Berry
Aralia Ravniana Heer
Araucaria bladenensis Berry
Araucaria marylandica Berry
Araucarites ovatus Hollick
Araucarites Zeilleri Berry
Arisaema cretaceum Lesquereux
Arisaema (?) mattewanense Hollick
Asplenium cecilensis Berry
Algites americana Berry
Baiera grandis Heer?
Banksia pusilla Velenovsky?
Banksites Saportanus Velenovsky
Bauhinia marylandica Berry
Betulites populifolius Lesquereux
Brachyphyllum macrocarpum Newberry
Brachyphyllum macrocarpum formosum Berry
Bumelia praenuntia Berry
Calycites alatus Hollick
Calycites obovatus Hollick
Carix Clarkii Berry
Carpites liriophylli Lesquereux
Carpites minutulus Lesquereux
Carpolithus cliffwoodensis Berry
Carpolithus drupaeformis Berry
Carpolithus floribundus Newberry
Carpolithus hirsutus Newberry
Carpolithus juglandiformis Berry
Carpolithus mattewanensis Berry
Carpolithus ostryaeformis Berry
Carpolithus septloculus Berry

Cassia insularis Hollick
Ceanothus constrictus Hollick
Celastrus arctica Heer
Celastrophyllum crassipes Lesquereux?
Celastrophyllum crenatum Heer?
Celastrophyllum elegans Berry
Celastrophyllum grandifolium Newberry?
Celastrophyllum Newberryanum Hollick
Celastrophyllum undulatum Newberry?
Chondrites flexuosus Newberry?
Cinnamomum crassipetiolatum Hollick
Cinnamomum Heeri Lesquereux
Cinnamomum membranaceum (Lesquereux) Hollick
Cinnamomum Newberryi Berry
Cissites formosus magothiensis Berry
Cissites Newberryi Berry
Citrophyllum aligerum (Lesquereux) Berry
Coccolobites cretaceus Berry
Cocculus cinnamomeus Velenovsky
Cocculus imperfectus Hollick
Cocculus inquirendus Hollick
Cocculus minutus Hollick
Colutea obovata Berry
Confervites dubius Berry
Cordia apiculata (Newberry) Berry
Cornus cecilensis Berry
Cornus Forchhammeri Heer
Crataegus monmouthensis Berry
Credneria macrophylla Heer
Crotonophyllum cretaceum Velenovsky
Cunninghamites elegans (Corda) Endl.
Cunninghamites squamosus Heer
Cupressinoxylon Bibbinsi Knowlton
Czekanowskia dichtoma Heer?
Dalbergia irregularis Hollick
Dalbergia minor Hollick
Dalbergia severnensis Berry
Dammara borealis Heer
Dammara cliffwoodensis Hollick
Dammara minor Hollick
Dammara northportensis Hollick
Dewalquea groenlandica Heer
Diospyros apiculata Lesquereux?
Diospyros primaeva Heer
Diospyros prodromus Heer?
Diospyros provecta Velenovsky
Diospyros pseudoanceps Lesquereux
Diospyros rotundifolia Lesquereux
Doryanthites cretacea Berry
Dryandroides quiercinea Velenovsky
Elaeodendron marylandicum Berry
Elaeodendron strictum Hollick
Embothriopsis presagita Hollick
Eucalyptus (?) attenuata Newberry
Eucalyptus Geinitzi Heer
Eucalyptus Geinitzi propinqua Hollick
Eucalyptus latifolia Hollick
Eucalyptus linearifolia Berry
Eucalpytus Schubleri (Heer) Hollick?
Eucalyptus Wardiana Berry
Ficus atavina Heer
Ficus cecilensis Berry
Ficus crassipes Heer
Ficus daphnogenoides (Heer) Berry
Ficus Krausiana Heer
Ficus Krausiana subsimilis Hollick
Ficus myricoides Hollick
Ficus reticulata (Lesquereux) Knowlton
Ficus sapindifolia Hollick
Ficus Willisiana Hollick
Ficus Woolsoni Newberry
Frenelopsis Hoheneggeri (Ettingshausen) Schenk?
Geinitzia formosa Heer
Gleichenia delawarensis Berry
Gleichenia gracilis Heer?
Gleichenia protogaea Debey and Ettingshausen
Gleichenia Saundersii Berry
Gleichenia Zippei (Corda) Heer
Guatteria cretacea Hollick
Gyminda primordialis Hollick
Hedera cecilensis Berry
Hedera cretacea Lesquereux
Hedera simplex Hollick
Heterofilicites anceps Berry
Hymenaea dakotana Lesquereux
Hymenaea primigenia Saporta
Ilex papillosa Lesquereux
Ilex severnensis Berry
Ilex strangulata Lesquereux
Illicium deletoides Berry
Juglans arctica Heer
Juglans crassipes Heer

Juglans elongata Hollick
Juniperus hypnoides Heer
Laurophyllum angustifolium Newberry
Laurophyllum elegans Hollick
Laurophyllum lanceolatum Newberry
Laurophyllum ocoteaeoides Hollick
Laurus antecedens Lesquereux
Laurus atanensis Berry
Laurus Hollae Heer
Laurus Hollickii Berry
Laurus nebrascensis Lesquereux
Laurus Newberryana Hollick
Laurus plutonia Heer
Laurus proteaefolia Lesquereux
Laurus teliformis Lesquereux
Leguminosites canavalioides Berry
Leguminosites convolutus Lesquereux?
Leguminosites coronilloides Heer
Leguminosites omphaloboides Lesquereux
Ligustrum subtile Hollick
Liriodendron attenuatum Hollick
Liriodendron morganensis Berry
Liriodendron oblongifolium Newberry?
Liriodendropsis angustifolia Newberry
Liriodendropsis constricta Hollick
Liriodendropsis retusa (Heer) Hollick
Liriodendropsis simplex Newberry
Liriodendropsis spectabilis Hollick
Lycopodium cretaceum Berry
Magnolia amplifolia Heer
Magnolia Boulayana Lesquereux
Magnolia Capellinii Heer
Magnolia Hollicki Berry
Magnolia Isbergiana Heer
Magnolia Lacoeana Lesquereux
Magnolia longipes Hollick
Magnolia obtusata Heer
Magnolia pseudoacuminata Lesquereux
Magnolia speciosa Heer
Magnolia tenuifolia Lesquereux
Magnolia Van Ingeni Hollick
Magnolia woodbridgensis Newberry
Malapoenna falcifolia (Lesquereux) Knowlton
Marsilea Andersoni Hollick
Menispermites acutilobus Lesquereux?
Menispermites Brysoniana Hollick
Microzamia? dubia Berry
Moriconia americana Berry
Myrica Brittoniana Berry
Myrica cliffwoodensis Berry
Myrica longa Heer
Myrica Zenkeri (Ettingshausen) Velenovsky
Myrsine borealis Heer
Myrsine crassa Lesquereux
Myrsine Gaudini (Lesquereux)
Myrtophyllum sapindoides Hollick
Nectandra imperfecta Hollick
Nelumbo Kempii Hollick
Nelumbo primaeva Berry
Ocotea nassauensis Hollick
Onoclea inquirenda Hollick
Osmunda delawarensis Berry
Osmunda novae-caesareae Berry
Paliurus integrifolius Hollick
Paliurus populiferus Berry
Panax cretacea Heer
Periploca cretacea Hollick
Persea Leconteana Lesquereux
Persea valida Hollick
Phaseolites manhassettensis Hollick
Phragmites ? cliffwoodensis Berry
Phyllites cliffwoodensis Berry
Picea cliffwoodensis Berry
Pinus Andraei Coeymans?
Pinus delicatulus Berry
Pinus mattewanensis Berry
Pinus protoscleropitys Holden
Pitoxylon anomalum Holden
Pitoxylon foliosum Holden
Pitoxylon Hollicki Knowlton
Pistia Nordenskioldi (Heer) Berry
Planera betuloides Hollick
Platanus Kümmeli Berry
Podozamites Knowltoni Berry
Podozamites lanceolatus (L. and H.) F. Braun
Podozamites marginatus Heer
Populus stygia Heer
Populites tenuifolius Berry
Premnophyllum trigonum Velenovsky
Protodammara speciosa Hollick and Jeffrey
Protophyllocladus lobatus Berry

Protophyllocladus subintegrifolius (Lesquereux) Berry
Quercus eoprinoides Berry
Quercus Hollickii Berry
Quercus Holmesii Lesquereux
Quercus Morrisoniana Lesquereux
Quercus ? novae-caesareae Hollick
Quercus severnensis Berry
Quercus sp. Berry
Raritania gracilis (Newberry) Hollick and Jeffrey
Rhamnites apiculatus Lesquereux
Rhamnus inaequilateris Lesquereux
Rhamnus novae-caesareae Berry
Rhus cretacea Heer?
Sabalites magothiensis Berry
Sagenopteris variabilis Velenovsky
Salix fluexuosa Newberry
Salix Lesquereuxi Berry
Salix mattewanensis Berry
Salix meekii Newberry
Salix purpuroides Hollick
Sapindus apiculatus Velenovsky?
Sapindus imperfectus Hollick
Sapindus morrisoni Heer
Sapotacites Knowltoni Berry
Sassafras acutilobum Lesquereux
Sassafras angustilobum Hollick
Sassafras progenitor Newberry
Sequoia ambigua Heer
Sequoia concinna Heer
Sequoia fastigiata (Sternberg) Heer?
Sequoia gracilis Heer?
Sequoia heterophylla Velenovsky
Sequoia Reichenbachi (Geinitz) Heer
Smilax raritanensis Berry?
Sphaerites raritanensis Berry
Sterculia cliffwoodensis Berry
Sterculia minima Berry
Sterculia prelabrusca Hollick
Sterculia Snowii Lesquereux?
Sterculia Snowii bilobatum Berry
Sterculia sp. Hollick
Strobilites inquirendus Hollick
Strobilites perplexus Hollick
Thuja cretacea (Heer) Newberry
Thyrsopteris grevilliodes (Heer) Hollick
Tricalycites major Hollick
Tricalycites papyraceus Newberry
Tricarpellites striatus Newberry
Viburnum Hollickii Berry
Viburnum integrifolium Newberry
Viburnum mattewanensis Berry
Widdringtonites fasciculatus Hollick
Widdringtonites Reichii (Ettingshausen) Heer
Widdringtonites subtilis Heer
Williamsonia delawarensis Berry
Williamsonia marylandica Berry
Williamsonia problematica (Newberry) Ward
Zizyphus cliffwoodensis Berry
Zizyphus elegans Hollick
Zizyphus groenlandicus Heer
Zizyphus Lewisiana Hollick?
Zizyphus oblongus Hollick

A CRITICAL STUDY OF THE FOSSIL BIRD *GALLINULOIDES WYOMINGENSIS* EASTMAN

R. W. SHUFELDT
Washington, D.C.

A number of years ago, in the *Geological Magazine* of London, Dr. Eastman described one of the most interesting and complete skeletons of a fossil bird that we have in this country.[1] This remarkable specimen (see Fig. 1) was taken in the Green River shales of Wyoming, near the town of Fossil, during the summer previous to the publication of the article, and it passed into the possession of the Museum of Comparative Zoölogy of Cambridge (Massachusetts), where it still forms a part of the collection of fossil vertebrata.

During the latter part of May, 1914, I met Dr. Eastman at the United States National Museum, where he was engaged upon a study of the fossil fishes belonging to that institution. He kindly suggested that I communicate with Professor Samuel Henshaw of the Museum of Comparative Zoölogy of Cambridge, and borrow, if possible, the slab containing this fossil bird, and make a more complete study of it than he had made when the specimen first came to him for determination. This suggestion I was glad to act upon; and in a few days, through the courtesy of Professor Henshaw, the original slab came to hand for my study and description.

First of all I made two perfect negatives of the specimen (8′×10′), reproducing it nearly natural size; the reproduction of a print from one of these forms the subject of Fig. 1 in the present article.

In his account of this fossil, Dr. Eastman speaks of it as "a nearly perfect skeleton of a gallinaceous bird" (p. 54), and had he adhered to that opinion, the place he thus assigned it to in the system would never have been questioned. However, he evidently,

[1] Charles R. Eastman, "New Fossil Bird and Fish Remains from the Middle Eocene of Wyoming," *Geol. Mag.*, London, VII (February, 1900), 54–58, Pl. IV (reduced rather more than one-third).

upon subsequent examination, was convinced that he saw other features presented by it, which led him to say, on the same page just quoted, that it was one of an extinct genus of "short-billed, stout-legged birds attaining the size of a gallinule, rail, or small coot, and resembling these forms in general character."

As the supersuborder Ralliformes has no especial affinity with the supersuborder Galliformes, this last statement distinctly contradicts Dr. Eastman's first reference as cited above.[1]

As will be observed by an examination of Fig. 1, the skeleton of this fossil presents many evidences of compression. Most of the bones are of a dark chocolate color, and all of them are considerably darker than the pale-gray matrix in which the specimen is imbedded. Some of the bones have retained their normal positions in articulation, while the remainder have, for the most part, been more or less dislodged from the places they occupied in life. Some were either not in sight at all, or became, to a greater or less extent, removed from the skeleton before the process of fossilization commenced. An excellent example of this is seen in a rib which lies removed from the nearest bone to it in the skeleton by a distance of 18 mm.

This specimen was evidently "cleaned up" by an ignorant collector, and in his misguided attempts to improve it by *scraping*, he has terribly mutilated the most important parts in sight. Thus the skull has been practically ruined, and the cervical vertebrae ground down so as to present merely a longitudinal sectional aspect. Dr. Eastman, in commenting upon this, says: "Depredations of this nature are wholly inexcusable and cannot be too severely censured" (p. 55).

The head and cervical portion of the spine are seen upon direct left lateral view, and are but slightly elevated above the level of

[1] R. W. Shufeldt, "An Arrangement of the Families and the Higher Groups of Birds," *Amer. Nat.*, XXXVIII, Nos. 455–56 (November–December, 1904), 833–57. The relation of these groups is given on p. 852. Dr. Eastman asked me if I did not think there was "some tinamou in the specimen." To which I replied that I did not. As a matter of fact, there is far less tinamou in this extinct fossil bird than there is gallinule. The shoulder-girdle, sternum, and pelvis of a tinamou are entirely different, as may be appreciated by comparing the skeleton of *Nothura maculosa* Temm. with Fig. 1 of the present article. I figured a skeleton of this tinamou in the article here cited (Fig. 3, p. 839).

the matrix. As referred to farther on, the dorsal and lumbar vertebrae are considerably out of position, while all the free ribs are, to a great extent, mixed up together. At least three of the left costal ribs or haemapophyses have retained their places in articulation and are in plain sight; they are the last three of the series on that side.

Passing to the pelvis, we are to observe that it is turned entirely over, so that almost a direct ventral view is obtained of it. Posteriorly, the left femur lies obliquely across it.

Its sacrum is nearly in line with the dorso-lumbar section of the spine; and as to the skeleton of the tail, all but the leading caudal vertebrae are entirely out of sight, although I am inclined to think that the severely ground-down chain of three or four little bones, seen 3.5 cm. to the right of the left tarso-metatarsus, are the partly exposed caudal vertebrae, though the pygostyle is not in view.

The cervical portion of the spine is arched far backward over the dorsum, which is often the case with dead birds found in nature at the present time, and which appears to be due to the mode of attachment of the dorso-vertebral ligaments.

In assuming this position, the skull was likewise carried backward, although its ligamentous attachment to the atlas has been, in part, freed.

Almost a direct left lateral aspect of the sternum is presented, and all this portion is beautifully exposed. Its characters are in plain view, and will be described in full farther on in this article.

The left coracoid has been but slightly dislodged from its coracoidal articular groove on the anterior part of the sternum, and is consequently seen practically *in situ* with respect to the latter bone. This is almost as true of the left scapula, for it occupies nearly a normal position—that is, with respect to its coracoid, the os furculum, and the sternum.

On the other hand, the right coracoid is entirely disassociated from all the remaining bones of the pectoral arch, and now, with its anterior surface exposed, it lies back of the os furculum, in contact with the two clavicular limbs of its arch. We have in view the antero-oblique surface of the furculum, and consequently we have a left latero-oblique side of its hypocleidium exposed.

The right scapula is entirely free, being in full view except the parts covered by the os furculum and the left coracoid which are in front of it, the former almost completely hiding its head. Somehow, its distal head came to get in front of the ends of the vertebral ribs of the left side (see Fig. 1).

With respect to the sternum, it is to be observed that its pair of left xiphoidal processes, as well as the extreme posterior tip of the carina, overlap the shaft of the right femur—the former entirely and the latter as far as the inner condyle.

Perfect in nearly all respects, the right pectoral limb is drawn forward in front of the trunk skeleton, it being crossed by the cervical vertebrae at the distal third of the humerus,[1] which latter has its palmar aspect exposed to view, while it is the anconal sides of the bones of the antibrachium and pinion which are exposed—the forearm and manus having twisted once round before settling down. Curiously enough, the interosseous space between the radius and ulna of this limb is filled in with dark, fossilized structures, as though the muscles of the forearm had become mineralized instead of having been destroyed either by putrefaction or maceration.

Both the ulnare and the radiale of the carpus are in sight, while the skeleton of manus is perfect.

With its longitudinal axis parallel to that of the fellow of the opposite side, the left humerus appears to be free, with its radial side exposed to view.

Passing to the pelvic limbs, they are seen to be nearly perfect, and are so, all to the patellae (which may have been small or not in sight) and some of the pedal phalanges, which will be enumerated farther on. Neither femur was freed at its pelvic articulation, the head, in each case, apparently being still in the cotyloid cavity of the pelvis of the respective sides, as in life, while all the articulations among the long bones below are but slightly out of place in any particular instance.

[1] Dr. Eastman evidently mistook this right pectoral limb for the left. That it is the one of the right side is made almost certain by the fact that the cervical vertebrae would naturally be between the two humeri, when the former was curved backward and the latter drawn forward and upward, as is the case here.

FIG. 1.—*Gallinuloides wyomingensis* Eastman. Reproduction from a photograph of the specimen *in situ*, made direct from the slab by the author; nearly natural size.

On the whole, these limbs are drawn out nearly directly backward, just as though the skeleton had been in running water, the stream passing posteriorward, and these pelvic limbs had, before finally settling down, drifted into the positions in which they were eventually preserved; while the pectoral limbs, influenced by the same current, perhaps periodically flowing to and fro, had previously *lodged* finally in the positions they now are in in their stony matrix. Naturally, the head and neck floated backward with the legs.

The longitudinal axes of the femora are quite parallel to each other; those of the tibio-tarsi are at a slightly open angle, which is also true of those of the tarso-metatarsi, that is, supposing the imaginary lines of their longitudinal axes to be extended toward the pelvis in each instance. The right femur has its anterior surface exposed; the left its latero-internal. In the leg, both fibulae are visible; and in the case of the one on the left side, its proximal head can be plainly seen in the cleft of the external femoral condyle intended for its accommodation and articulation.

Notwithstanding the fact that the distal condyles are very prominent and the intercondylar valley rather deep, the right tibio-tarsus and fibula evidently have their direct posterior aspects exposed, with the fibula next to the median plane. In other words, these two bones, maintaining their articulatory relations, have once rotated over on their longitudinal axis, while the prominence of the distal condyles, over what they naturally possess on this posterior aspect of the tibio-tarsus, has evidently been produced by transverse pressure.

In the case of the left tibio-tarsus, which likewise has maintained its mutual and normal articulatory relations, it presents its antero-externo-lateral aspect.

Either tarso-metatarsus has its almost direct anterior surface exposed, and these are, in each case, thrown but slightly out of place with respect to their articulations with the tibio-tarsi.

The phalanges of the right pes are exposed almost entirely on mesial aspect, and the bones are all present, the joints of the second toe being seen on their dorsal aspects, which, with the exception of hallux, is the case with all the phalanges of the left foot. Here some of the joints are missing, having been broken off and lost. This is

the case with the anterior half of the third phalange of the mid-anterior toe, as well as its entire ungual joint. In the case of the outer toe, all is lost beyond the posterior moiety of the third phalange; finally, the osseous claw of hallux, in the case of this foot, is gone.

All the bones of the hyoidean apparatus are either entirely hidden in the matrix, or else they have drifted away from the skeleton prior to the time of its fossilization. In the left orbit, the circlet of sclerotal platelets are still *in situ* and completely fossilized. The lower mandible is duly articulated, and the bony jaws are tightly closed together.

Dr. Eastman presented a number of accurate measurements of this specimen in his article (p. 56), which were as follows:

TABLE OF MEASUREMENTS

(All *lengths* given in millimeters)

	Mm.		Mm.
Head	48	Manus	46
Scapula	48	Femur	42
Coracoid	27	Tibia	58
Furculum	33	Tarso-metatarsus	34
Christa sterni	58	I. Digit (7, 4)	11
Humerus	47	II. Digit (11, 8, 6)	25
Ulna	49	III. Digit (12, 10, 8, 6)	36
Radius	45	IV. Digit (7.5, 5.5, 4, 4, ? 4)	25
Height of knee-joint (estimated)	90		
Total height (estimated)	220		

To these I may add some of my own measurements (also in millimeters), which are:

SUPPLEMENTARY TABLE

	Mm.
Length of mandible (approx.)	38
Height of skull (cranium)	20
Longitudinal diameter of left orbit	9
Length of carpo-metacarpus	25
Proximal phalange of index digit	12
Distal phalange of index digit	9
Pollex digit	11.5
Medio-longitudinal length of pelvis	43
Length of pubic bone	32
Greatest width of posterior moiety of pelvis	29
Depth of sternum (anteriorly)	30

The skull.—As already pointed out above, this part of the skeleton has been rendered almost useless through the scraping given it by the collector. Still, there is something to be said of it, for even its outline teaches a little, though in regard to this, Dr. Eastman made no comments whatever, beyond deploring the mutilations which have been committed.

Taken in connection with the mandible, the form of the skull of this fossil bird was distinctly of the gallinaceous type, which will be readily appreciated by comparing it with that of any true and average grouse, partridge, or pheasant. Several of these are shown in previous papers of mine (see footnote 1). In general, the characters are the same in all of these. In the specimen under consideration, the external narial aperture was of moderate size, and possessed the usual elliptical outline; the quadrato-jugal bar was slender and straight, while the postfrontal and squamosal processes were united at their anterior apices as in *Bonasa*. A lacrymal bone was of some size, and had a form such as we see in *Phasianus colchius*,[1] while a nasal beyond it closely resembles that element of the cranium in any average tetraonid that has its maxillary process narrow and delicately formed.

There is a good character in the antero-terminal portion of the superior maxillary or upper mandible, for it has a contour that is strictly gallinaceous in all respects,[2] and is essentially quite different from anything of the kind we find either in the rails or in gallinules.

Vertebral column.—There were fifteen vertebrae in the cervical division of the spine before we come to one which is considered to be the first dorsal vertebra, as it has a pair of true ribs connecting with the sternum by means of costal ribs. This is the sixteenth of the spine, and its ribs and the connecting costal ribs or haemapophyses can easily be made out in the specimen. Whether the fifteenth bore a small pair of free ribs cannot be stated positively, as they are not in sight in that vertebra.

[1] R. W. Shufeldt, "*Osteology of Birds*," State Museum Bull. 130, N.Y. State Museum, Albany, 1909, *Gallinae*, Pl. 2, Fig. 18.

[2] R. W. Shufeldt, "Observations upon the Morphology of *Gallus bankiva* of India," *Jour. Comp. Med. and Surg.*, New York, July, 1888, Vol. IX, No. 4, art. 21, pp. 343–76, 30 figures in text (pmx.).

The dorsal portion of the spine, the thoracic ribs, and the costal ribs are in such a demoralized condition that it would be quite unsafe to make any positive statements in regard to them. There seem to be, however, two free vertebrae just in advance of the pelvis, and each has its centrum rotated into view. In most grouse and other gallinaceous forms there is a single vertebra between the pelvis and the four which coössify into one piece in the dorsal series. If this were the case with respect to the specimen under consideration, and we find, as I say, two free ones anterior to the pelvis, it may be explained by the fact that the fossil skeleton belonged to a subadult individual, which died before the co-ossification of the dorsal vertebrae took place. I do not say that this was the case; but I will say that, were I to find all the rest of this skeleton of this fossil to be typically gallinaceous—and all the dorso-lumbar vertebrae were hidden from sight—its dorsals were four and all in one bone, while between it and the pelvis would be found another single, free vertebra. This would surely be the case were the individual an adult bird.

The ribs were slender, and those in mid-series apparently bore "epipleural appendages," as at least in the case of one rib the process can be seen; they are never very prominent or strong in the *Gallinae*.

In the rails and gallinules the number of cervico-dorsal vertebrae between the skull and the pelvis is greater than in any of the true gallinaceous forms, while in the former the dorsal vertebrae never unite to constitute a single bone.[1]

The pelvis.—Owing to the fact that the ventral aspect of this bone alone is exposed, only its characters upon that aspect can be touched upon. These indicate that the gallinaceous nature of them is very distinctly marked, and that this pelvis would answer for any grouse of average size, such as *Bonasa umbellus* for example. These characters, too, are better shown in such a pelvis as the one possessed by *Centrocercus* than is the bone in such a bird as *Thaumalea picta*. Were its dorsal aspect exposed, in the fossil specimen here being considered, it would closely resemble the pelvis of *Bonasa*

[1] R. W. Shufeldt, "Osteology of *Porzana carolina*," *Jour. Comp. Med. and Surg.*, New York, IX (July, 1888), No. 3, art. 17, pp. 231–48. (Seven figures.) See p. 7.

umbellus, which I figure in my *Osteology of Birds*, published by the New York State Museum at Albany (Pl. VI, Fig. 26).

Anteriorly, the bone is broad, with its iliac borders rounded, the lateral margins being concaved inward toward the sacrum. This latter, on its ventral aspect, presents a longitudinal, median furrow, which extends posteriorly as far back as a point opposite the acetabulae. This, taken in connection with the decided enlargement of the sacrum between the cotyloid cavities and its anterior termination, presents us with a very common character of the pelvis in gallinaceous birds generally. It is well shown in the pelvis of *Centrocercus*. In these gallinaceous birds, too, the anterior sacral vertebra is always prominently produced downward through the form of its centrum, a feature to be noticed in the pelvis of any typical tetraonine species.

Posteriorly, this pelvis is likewise broad, with the free margins of its ilia behind unnotched in any way. The pubic elements are slender in form and of nearly uniform proportions throughout, while posteriorly they extend for some little distance beyond the ilia. In fact, they agree, as do all the other characters of this pelvis, with the corresponding ones in the pelvis of any typical tetraonine species of the present time (Fig. 2).

In the gallinules and other rail-like birds, the pelvis possesses an entirely different character, it being much narrower throughout, with anteriorly truncated ilia and other features, which are clearly to be observed in my figure of the pelvis of *Porzana carolina* referred to above.

Further, I have stated that "in a great many particulars, *Porzana*, *Crex*, *Rallus*, *Ionornis*, *Fulica*, and *Gallinula* agree in their osteology,"[1] and this, in all probability, is true of the remainder of their morphology.

The sternum and shoulder-girdle.—Little need be said by way of description of the sternum of this specimen, for it is so typically

[1] R. W. Shufeldt, "On the Osteology of Certain Cranes, Rails, and Their Allies, with Remarks upon Their Affinities," *Jour. Anat. and Phys.*, London XXIX (October, 1894), N.S., IX, Part I, art. 5, pp. 21–34. Text figures. A paper on the descriptive osteology of all the species constituting this group of birds in North America has recently been accepted for publication by the *Anatomical Record* (Wistar Institute, Philadelphia) and will appear in due course.—R. W. S.

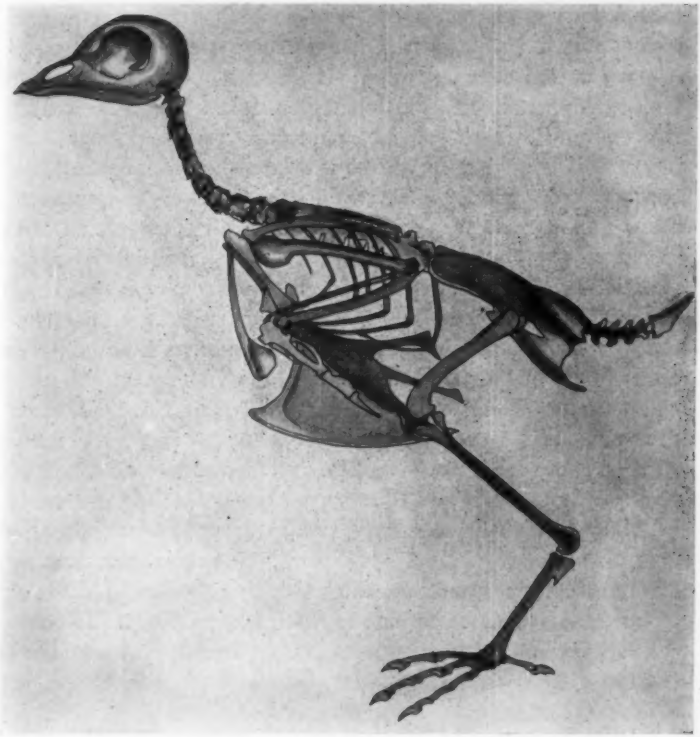

FIG. 2.—Skeleton restoration of the fossil bird *Gallinuloides wyomingensis* Eastman. Made and drawn by the author, guided by the fossil specimen belonging to the Museum of Comparative Zoölogy of Harvard University, kindly loaned him for the purpose. For amount of reduction compare with measurements given in the table above. In some of the bones their actual morphology is closely given. The outline of the skull agrees with the specimen. The cervical vertebrae as drawn are intended to number some fourteen or fifteen. In drawing the pelvis, assistance was given through study of the general tetraonine form of that bone. The free caudal vertebrae and pygostyle are as they occur in related gallinaceous birds. In the case of the ribs, they are in part as in the specimen, while the sternum and bones of the shoulder are entirely so, and agree, in all particulars, with those bones in the specimen of *Gallinuloides* here considered. With respect to the skeleton of the pectoral and pelvic limbs, the bones have the general outline of the corresponding ones, in any particular instance, in the original, and the proportionate lengths are actual.

In making this drawing, I intentionally omitted to include the limbs of the right side, as nothing would be gained by showing them, and they would needlessly complicate the figure. Measurements of the long bones and others are given in the text; and from these measurements, taken in connection with this drawing and other data presented, a very complete conception of the morphology of the skeleton in this fossil bird may be obtained.

gallinaceous in character that similar ones have been described many times in various works on avian osteology. Moreover, with its deep carina; concaved anterior border; a pair of long, somewhat slender, xiphoidal processes on either side, with their expanded, free extremities a prominent manubrial process of quadrilateral form; and finally, a very narrow sternal body, and short costal borders where the costal ribs articulate—all these characters, and a few minor ones, are plainly to be seen in the sternum of this specimen.

This style of sternum agrees in all particulars with that bone as we find it in *Bonasa umbellus*, exhibiting various modifications in the style of sternum found in the genera and families of all gallinaceous birds, in all parts of the world, as for example pheasants, guans, grouse, partridges, guinea-fowls, quails, turkeys, and all their allies and congeners.[1]

Had I seen the sternum of this fossil bird and no other part of its skeleton, I could, without the slightest hesitation, and without having laid eyes upon the coracoids, scapulae, or the os furculum, have described them in all detail. No fowl, living or extinct, possesses a sternum in all respects agreeing with that bone in *Gallinuloides wyomingensis* without having an os furculum which is of the U-shaped pattern, with a large, subtriangular hypocleidium. The clavicular limbs are of nearly uniform caliber, and the free superior ends are but very slightly enlarged. Both *Gallus* and *Bonasa* possess an os furculum of identically the same character, while *Gallinula*, *Fulica*, *Rallus*, and the rest, possess a very different form of one, and one that is more or less compressed antero-posteriorly, without any hypocleidium worth mentioning.

Either coracoid is large, above the average in length for ordinary birds of this size, apart from the gallinaceous group, with the sternal

[1] Richard Owen, *Comp. Anat. and Phys. of Verts.*, II, 27; R. W. Shufeldt, "Osteology of Birds," New York State Museum Bull. 130, p. 183, Figs. 8 and 9 (*Gallus bankiva*); Max Fürbringer, *Ueber Morph. und Systematik der Vögel*, II, Table VI, Figs. 43, 44, 45; on the same plate these may be compared with the sternums of *Fulica*, *Rallina*, and *Crypturus*, in order to exemplify the differences between the galline sternum and the bone as it occurs in rails, gallinules, and tinamous; A. Chauveau, *Comp. Anat. of the Domestic Animals*, p. 113, Fig. 73; T. H. Huxley, *Anat. Vert. Animals*, p. 241, Fig. 81; W. K. Parker, Art. "Bird," *Encyclo. Brit.*, 9th ed., III, 720.

end but moderately expanded, and the head of the bone of a corresponding degree of development.

The inferior or lateral external process is practically very small and this is likewise the case with the "praecoracoidal process" at its superior extremity. With respect to the latter, Dr. Hans Gadow has remarked that this is "but very small or absent in *Apteryx*, *Tinamous*, *Steganopodes*, *Gallinae* and *Passeres*."[1] In its general character, this coracoid agrees closely with that bone as found in the extinct fossil species of *Palaeortyx* and *Palaeoperdix*, as described by Milne-Edwards, Lydekker, Gervais, Depéret, and others.[2]

A scapula is a long, slender, and narrow bone, but slightly curved, and with a small, nib-like expansion at the distal end, which is broken off in the specimen, leaving only its impression in the matrix. In short, the pectoral arch in *Gallinuloides wyomingensis* is quite typically gallinaceous, and essentially agrees with the pectoral arch in the skeletons of existing species and genera of North American *Tetraonidae*, especially with that part of the skeleton in *Bonasa*.

Skeleton of the limbs.—The long bones of the extremities exhibit in a few instances some flattening and slight distortion as the result of pressure. This has not, however, altered or concealed their various characters, but may be clearly made out in most instances. This is particularly the case with the skeleton of the pelvic limbs, which agree, in all respects, with the corresponding bones in the skeleton of an average grouse. When I say this, I refer especially to the tibio-tarsi and metatarsi, which are quite typical. It also had a grouse's wing, in so far as its skeleton goes, as may be easily proved, not only by such characters as have been preserved, but by the relative proportional lengths of the bones of the brachium, antibrachium, and manus. These relative proportional lengths are of some considerable value in making such comparisons, as, within

[1] *A Dictionary of Birds*, by Alfred Newton, assisted by Hans Gadow, with contributions from Richard Lydekker, Charles S. Roy, and Robert W. Shufeldt, p. 857 (footnote).

[2] Compare with the coracoid of *Palaeortyx maxima* of Lydekker in *P.Z.S.* (1893), p. 520, Pl. XII, Fig. 11; see also my figures of the coracoid and the os furculum of *Tympanuchus* in Hayden's 12th *Ann. Geol. Surv. of the Terr.*, p. 716, Pl. XII, Figs. 86 and 87.

certain limits, they hold true for members of the same family, and in several families differ very widely.

CONCLUSION

The extinct fossil bird which has been very fully considered in the present paper was one rather smaller than the North American ruffed grouse (*Bonasa umbellus*), to which it was quite closely affined. Were it in existence today, its place would have been in the family *Tetraonidae*, and near *Bonasa*, *Canachites*, and *Lagopus*, with which forms it holds many, indeed all, tetraonine skeletal characters in common. That it was a bird possessing strong volant powers is abundantly shown by the deep keel to its sternum, and the powerful development of its pectoral arch and wing; these offer ample evidence of this fact. Without doubt it had a flight quite coequal with that of any ordinary grouse.

This form was in no way related to the *Rallidae*, or any similar group, and certainly not to the gallinules. Moreover, when we come to find early Eocene forms of the *Tetraonidae* that exhibit in their skeletons a departure from the true tetraonine stock, it will not be a form of bird having in its skeleton paludicoline characters, and particularly not ralline ones. No such alliances have existed at any time in the world's history.

Annectent forms, possessing a good proportion of tetraonine or galline characters in their generalized organizations, will also exhibit skeletal characters connecting them with the pigeons and their near allies (*Columbae*), and such birds are still found to exist in the world's avifauna, as witness the sand grouse and others (*Syrrhaptes paradoxus*). In fact, the pigeons and fowls, as we know, possess many morphological characters in common at the present day.

As to finding the fossil remains of a true gallinaceous bird in the Green River shales of Wyoming (Middle Eocene), it need not surprise anyone, for true grouse forms occurred in corresponding formations elsewhere, not only in this country but in Europe. This is likewise true of the *Phasianidae*, a matter which I have abundantly proved in a memoir on the subject recently published entitled "Fossil Birds in the Marsh Collection of Yale University," and published in the *Transactions of the Connecticut Academy of Arts and Sciences*, XIX. (February 1915), 1–110.

The generic name *Gallinuloides* is a very misleading one as applied to the present bird, and matters have not been improved by the creation of a family *Gallinuloididae*.[1]

This bird, as I have remarked above, was a true grouse; but whether it can be placed in any existing genus of our North American *Tetraonidae* is another matter. It belongs in the near neighborhood of *Lagopus* and *Bonasa*, and probably in a genus of its own. For such a genus, did the "Canons of Zoölogical Nomenclature" (Canon XXXI) admit of it, I would suggest the name of *Palaeobonasa*. And if at any time in the future such changes are made, under additional rules to meet cases of the kind, this extinct species should then be known as *Palaeobonasa wyomingensis*.[2]

[1] Frederic A. Lucas, No. 4, "Characters and Relations of *Gallinuloides wyomingensis* Eastman, a Fossil Gallinaceous Bird from the Green River Shales of Wyoming," *Bull. Mus. Comp. Zoöl. at Harvard Coll.*, XXXVI (1900–1901), 79–84. Illustrated.

The author of this well-known paper says of the fossil bird here being considered that "its galliform nature is obvious at a glance"; and while he states that it was a "bird of about the size of a ruffed grouse" (which is correct), he falls into the error of stating that "the majority of its structural resemblances are with the curassows and with the genus *Ortalis* amongst those birds," and the still more remarkable error in the statement that "the bird presents no points of affinity with any of the American grouse, still less with any of the *Odontophorinae*."

The writer is very careful to make no reference whatever to the fact that this fossil bird is in no way related to the gallinules; nor does he make any effort (through change of name) to disabuse the mind of the palaeontolɒgists of the incorrectness of that reference. When any animal has been incorrectly classified, it is a distinct advantage to science to rename it, as it is relegated to the group to which it in reality belongs. Moreover, Lucas emphasizes the error made in the original reference by suggesting the creation of the family *Gallinuloididae*, which has, unfortunately, already passed into palaeornithological nomenclature (*A.O.U. Check-List of North American Birds*, ed. 1910, p. 388, etc.).

It may be said here that I figure (natural size) the trunk skeleton of a specimen of *Ortalis macalli* in my *Osteology of Birds*, and give an account of the skeleton of this species (p. 240, Pl. 4, Fig. 21). As compared with the fossil, especial attention is invited to the broad ribs, short and wide external xiphoidal processes of the sternum, and the small hypocleidium of the os furcula in *Ortalis*.

[2] Gen. name = Gr. παλαιός, ancient, and Sp. name, Gr. βόνασος, a wild bull. *Bonasa* was so named on account of the "drumming" practised by the bird at certain times, which has been considered by some to sound like the bellowing of a bull; in other words, an ancient form of *Bonasa*. As I have elsewhere shown, *Bonasa*, of all our North American grouse, comes nearest to the quails and partridges, and it is quite likely that this extinct species possessed some osteological characters in its skeleton which would indicate such an affinity still more plainly.

There have not been many fossil forms of ralline birds described for North America up to the present time, while typical gallinaceous species are, as I have said, by no means rare. Over twenty years have passed since I described *Crecoides osbornii*, a species I then considered as being related to the genus *Crex* among the *Rallidae*.[1] No fossil gallinules have been found anywhere apparently, the nearest form being *Porphyrio mackintoshi*, from the Pleistocene of Queensland, Australia, a specimen which I have not seen.[2] The fossil remains of several extinct forms of *Notornis*, however, have been described, and about five species of *Fulica*, from various and widely separated parts of the world, one of which is from the Pleistocene of Oregon (*F. minor* Shuf.).

[1] R. W. Shufeldt, *Jour. Acad. Phila.*, XI (1892), 412.

[2] De Vis (p. 193, note).

GROUND-ICE WEDGES

THE DOMINANT FORM OF GROUND-ICE ON THE NORTH COAST OF ALASKA

E. DE K. LEFFINGWELL

It is a widely known fact that the ground in Arctic and sub-Arctic regions is permanently frozen to a great depth, only the upper few feet thawing in summer. Nearly all observers have reported the presence of bodies of more or less clear ice underlying the surface of the ground, usually immediately below the limit of annual thawing. Ordinarily the ice is represented as existing in horizontal beds of some thickness and lateral extent, but the observations of the writer upon the north shore of Alaska show that there, at least, the ground-ice occurs chiefly in a network of vertical wedges, surrounding isolated bodies of the tundra formation.

Although this form of ice is the dominant one in the area studied, it is not held that it is the only one, nor that the theory of its formation will fit every case. It seems quite certain that there are several different kinds of ground-ice, each one having originated in a different way.

During the summer of 1914 several dozen photographs of the ice were made, but most of them were damaged later by water, so that the writer has to depend chiefly upon sketches which were often hastily made. Fortunately Mr. P. S. Smith, of the United States Geological Survey, had, some years ago, secured photographs of ground-ice on the Noatak River, and one of these photographs illustrates the wedge-form ice which is the subject of this paper (Figs. 1, 2).

The chief difficulty encountered in the study of the tundra formation arises from faulty exposures. The ground being of material only consolidated by frost, a short exposure to the summer air will cause slumping and consequent masking of the details. It is only where wave or river action has undermined the face of a bank, so that large blocks break off, that good exposures are formed. As

FIG. 1.—Ice wedges, Noatak River. Photograph by P. S. Smith, U.S. Geological Survey.

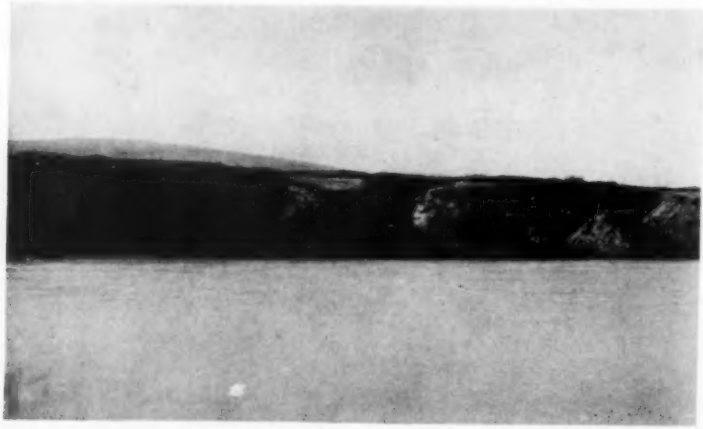

FIG. 2.—Another view of exposure shown in Fig. 1. Photograph by P. S. Smith, U.S. Geological Survey.

soon as slumping has taken place, erroneous conclusions may be drawn as to the distribution of the ice, scattered outcrops being interpreted as exposed parts of a single bed.

The upper surface of the ground-ice is usually only a foot or two under the surface of the tundra. Consequently in an area which has discontinuous bodies of ice separated by masses of muck, etc., there will be the least amount of material for slumping exactly where the ice occurs. The ice melts back under the overhanging turf, forming a cave, but at either side the muck will slump from

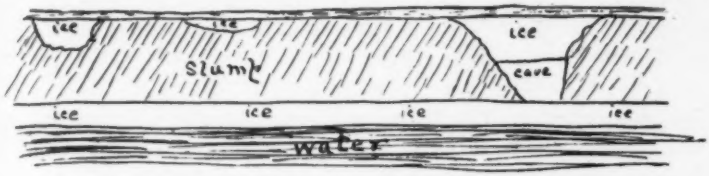

FIG. 3.—Exposure of a bank showing an apparently continuous thick bed of ice

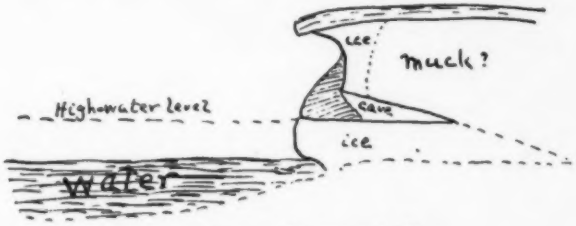

FIG. 4.—Structure of exposure in Fig. 1

the grass roots. Thus, wherever the surface of the bank is exposed, ice is likely to be seen, and observers are led to believe that a continuous body of ice underlies the whole area.

In addition to the erroneous impression as to lateral extent, the conclusions as to thickness are also often faulty. A winter's snow drift against the foot of a bank may be covered by slumping and later exposed, apparently showing a thickness of ice only limited by the height of the bank. The same may be true of river- or sea-ice. An illustration is given of an apparently continuous bed of heavy ice which the writer examined carefully for a quarter of a mile before learning its true nature (Figs. 3 and 4).

The waves had undercut this bank the summer before, making a long, low cave, perhaps ten feet deep. During the following winter this cave had been flooded at high tide and partially filled with ice. Early in the summer the face of the bank had been masked by slumping, leaving only a few glimpses of true ground-ice under the turf. Shortly before the time of observation the lower part of the bank had been washed clear of débris, exposing the continuous layer of new sea-ice. This appeared to be ground-ice, when coupled with the scattered exposures of undoubted ground-ice above. Luckily the cave was exposed to view at one point, so that the mistake in interpretation could be corrected.

The writer went into the field in the summer of 1906 with the idea that the coastal ground-ice occurred in horizontal sheets, and in consequence of faulty exposures did not learn its real distribution until 1914. During the first eight summers, although the ground-ice was examined at every opportunity, little insight was gained into the method of its formation. There has been no opportunity to go anew through the literature before writing this paper, but such illustrations as are at hand do not bear out the inferences drawn from them as to large horizontal beds of ice.

The usual theory advanced in the literature is that bodies of snow or ice were buried by peat or wash material and thus preserved. The writer sought to interpret the Alaskan coastal ground-ice in the light of this theory, but could neither postulate a satisfactory source for the ice, nor find any workable hypothesis to account for its preservation. It was not until the summer of 1914 that the fact was forced upon him that most of the ice was formed in place in the ground. A vertical wedge of ice within a peat bed first drew his attention to the fact; for such a dike of ice could not have stood up in the air for the hundreds of years that were necessary for the formation of the peat (Fig. 5).

FROST CRACKS

During the Arctic winter, frequent reports are heard, coming apparently from the ground. Often the sound is accompanied by a distinct shock, which is in fact an earthquake of sufficient intensity to rattle dishes, etc. One is justified in ascribing this phe-

nomenon to the cracking of the frozen ground during the winter's contraction. The writer has spent six winters in the region under discussion, living most of the time upon the tundra, which is chiefly underlain by muck. Frequent camps have been made upon other formations, such as sands and silts, and the impression carried away is that the sound of the cracking ground was heard everywhere. This has been confirmed by a prospector who has lived nearly thirty years in the country.

It was at first thought that the reports were caused by the cracking of hard snowdrifts, but the fresh cracks in these drifts were seen to run into the ground below. When the snow melts in the summer,

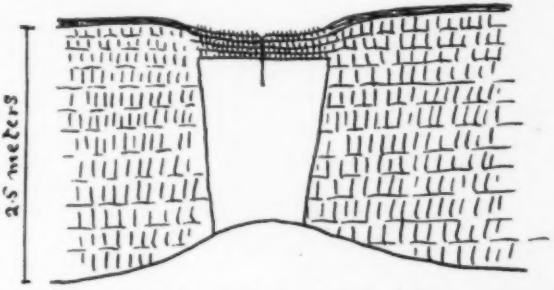

FIG. 5.—A large ice wedge in peat beds. The peat beds are not upturned. The ice is capped by growing moss.

fresh open cracks can be seen cutting across all the tundra formations, even mud and growing moss beds, and dividing the surface into polygonal blocks; these cracks resemble mud cracks but are of a larger size. The blocks have an estimated average diameter of about 15 meters, and have a tendency toward the hexagonal form, although rectangles and pentagons are often developed.

Occasionally a crack is seen to run across a flat surface with no associated features, as is illustrated in Fig. 6, but usually it is accompanied by a distinct topography. Either the crack lies in a gentle depression which surrounds an elevated polygon block, or it runs between two parallel ridges which surround a depressed block. These features do not vary from block to block, but each is locally developed over a considerable area. The "elevated blocks" have

seldom a relief of more than one foot, but that of the "depressed blocks" may be twice as much.

The parallel ridges form shallow reservoirs, very similar to those of the block system of irrigation, especially when they take a rectangular form, as is often the case. They often contain ponds and are always swampy, so that one keeps to the ridges for dry footing when crossing such an area (Figs. 7 and 8).

FIG. 6.—A frost crack on the surface of a recently drained area.

FORMATION OF ICE WEDGES

The open frost crack is in a favorable position for being filled with water during the melting of the snow, for most of them lie in depressions upon a flat surface. Even those that by chance get no water probably become filled with ice crystals deposited by the damp air, by internal "breathing." The crack, being filled with solid ice from the freezing of the water, or containing much ice in the form of frost crystals, thus contains a narrow vein of true ground-ice in the portion which lies below the depth reached by the annual thawing. When the frozen ground expands under the summer's heat, the readjustment to the strain may take place in four ways: (1) The pressure may melt the ice, so that the crack is closed again. (2) The formation

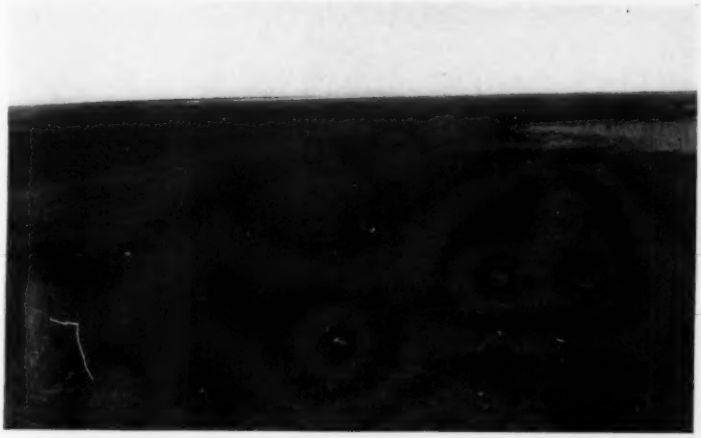

FIG. 7.—A frost crack lying between parallel ridges which inclose depressed polygon areas.

FIG. 8.—Frost cracks, parallel ridges, and block ponds

may be sufficiently elastic to absorb the strain, so that no deformation occurs. (3) The formation may be deformed and bulged up, either as a whole or locally along the edge of the ice wedge. (4) The ice may be deformed.

If the summer's strain has been relieved by readjustment of the material within the polygon block, the next winter will again bring about the conditions which caused the first cracking of the ground. Even if the first crack is full of ice, it may be still a plane of weakness for tensive strains; and this will be especially true if the crack has been only partially filled. Granted that it is a plane of weakness, the new cracks will open at the same place and a constantly growing body of ice be formed at the locus. That this is the ordinary case in tundra formations is seen in the constant association of ice wedges with definite loci of frost cracks.

Thus the growth of the ice goes on from year to year, possibly failing during mild years, when it may not be necessary for all the cracks to open in order to relieve the strain. If the process were not hindered, the upper edges of the wedges would eventually come into contact, thus completely inclosing a cone-shaped mass of the original ground-material. It is conceivable that the process might still go on by bulging up the ice, as it at first bulged up the ground. It is thus within the limits of possibility that a continuous horizontal bed of ice should be formed in this manner, but nothing approaching this possible stage has been observed by the writer.

The thinnest wedge that has come under observation was about a foot wide, but cracks have been seen accompanied by no surface manifestations (Fig. 6) and with no visible ice below them. No doubt the intervening stages exist, especially in an area such as a recently drained lake bottom, where the process is being initiated. The thin veins have nearly parallel sides and flat tops, as can be seen in Figs. 9 and 10. As the ice increases in size, it becomes more wedge-like in form, since the growth is greatest near the top where the crack opens widest. There is a tendency in the large wedges to spread out under the surface of the ground (Fig. 11). This is exaggerated in oblique sections, as is shown in Fig. 12.

The bottom of an ice wedge has never been observed by the writer. Most of the banks on the north shore of Alaska are less

than ten feet high and the bottom is nearly always concealed by slumping. The maximum vertical dimension observed is about 3 meters, but the wedge had a thickness sufficient to have carried it two or three times as far down before pinching out. The ultimate

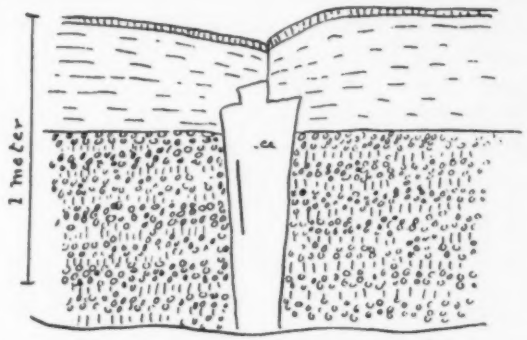

FIG. 9.—A narrow ice wedge in a deposit of mixed clay and ice granules. An open crack within the wedge.

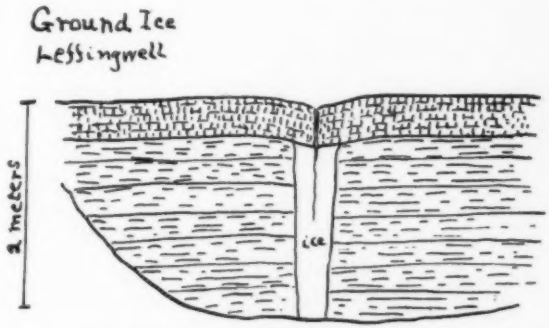

FIG. 10.—A narrow ice wedge in muck beds; an open frost crack runs through the turf and into the ice.

depth must depend upon the depth of annual change in ground temperature in the region. The constants are so uncertain that it is impossible to make a close calculation of this depth. For the purposes of this paper the depth of the ice wedges is assumed to be from 8 to 10 meters.

The upper surface of the ice is usually less than two feet under the ground in muck formations, about the limit to which the summer's thawing penetrates. This surface is usually horizontal, or undulating with the surface of the ground. One or two exposures showed a dome-shaped surface, and another, a central projection above the general surface (Fig. 9). Some more complicated exposures are shown in Figs. 12 and 13. The overlying material is usually muck capped by a few inches of turf. Occasionally it is peat capped by growing sphagnum (?) moss.

Without going deeply into the question of the crystallization of ice, it may be remarked that ice resulting from snow (and glaciers)

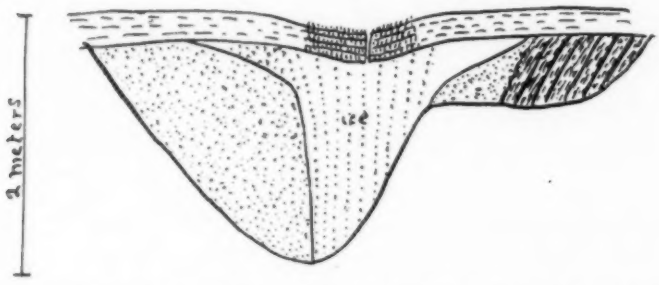

FIG. 11.—A large ice wedge which spreads out under the surface of the ground. The vertical lines indicate rows of whiter ice full of air bubbles. The material on either side is sand. To the right are upturned muck beds.

is granulated, but that from standing fresh water is vertically prismatic. Sea-ice is different from both, but very little has been written upon the subject. The writer's own observations are that sea-ice loses its salt at temperatures approaching 0° C. and becomes honeycombed, showing a general vertical structure, but decidedly different from that of fresh-water ice.

A fresh transverse section of an ice wedge shows a face of whitish ice with numerous parallel vertical markings (Figs. 11–14). These markings are usually of whiter ice which is seen to contain an unusual amount of air bubbles. It is often visibly granular, yet shows a general vertical structure, and breaks up into short, irregular pieces when allowed to melt slowly in the shade.

At the sides of the wedge the markings of the ice are inclined from the vertical and approach parallelism with the sides. Since the growth seems to occur near the center of the wedge, the older lines, though originally vertical, are later spread apart at the top. Oblique sections of wedges will give exaggerated angles of inclination or even curves (Figs. 14 and 15).

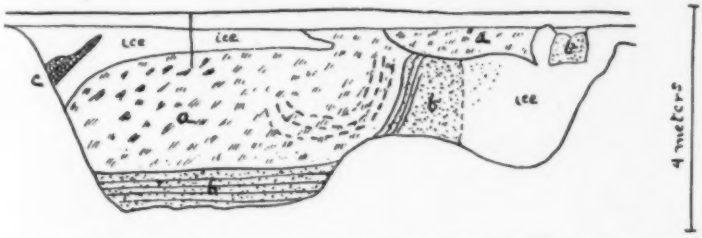

FIG. 12.—A complicated exposure: *a*, disturbed muck and clay; *b*, clay; *c*, peat; at *d* a frost crack runs through the turf and ice.

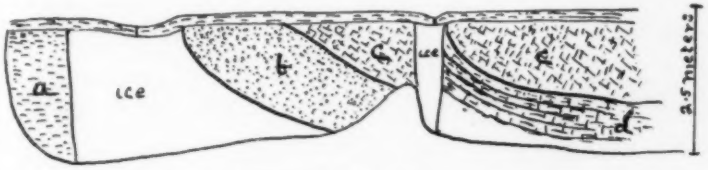

FIG. 13.—A complicated exposure: *a*, clay; *b*, sand; *c*, peaty detritus, no structure visible; *d*, peaty detritus.

In several cases open cracks were seen running down for a few feet into the ice, often being a prolongation of an open frost crack in the tundra above. Once or twice open cracks were seen within the body of the ice, so that a thin sheath knife could be shoved in for several inches (Figs. 9 and 10). Near the edge of a bank these open cracks may become drainage lines for surface waters, so that a tunnel is developed within the ice (Fig. 16). As the tunnel widens the roof caves in and a deep gully is formed in the bank. These gullies work back and around the polygon blocks, making the neighborhood of an old bank rather difficult walking.

The typical formation associated with ice wedges in the region under discussion is muck, a black mud containing much vegetable matter more or less decomposed. It varies from a peaty detritus, which shows signs of having been waterlaid, to sand or mud mixed with a varying amount of decaying vegetation. Undisturbed sections of this muck will usually show horizontal bedding. Occasionally sand or a slimy clay was seen under the muck where a good exposure revealed the lower strata (Fig. 12). As the ice wedge grows in thickness and presses against the edges of the cleaved muck and sand beds, they may become upturned and in time bent to the

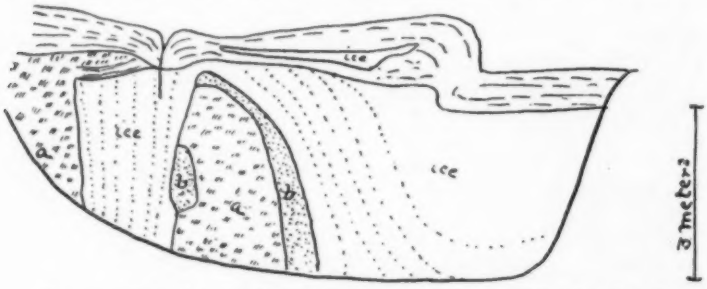

FIG. 14.—Two joining wedges; the one on the right is cut obliquely. The dotted lines represent lines of air bubbles within the ice. *a*, muck and clay, much disturbed; *b*, sand. See Fig. 15.

vertical or even beyond (Figs. 12, 17 and 18), causing the ridges which often run along either side of the frost crack in "depressed block" areas. In "elevated block" areas, the process is not so easily understood. It may be that the block as a whole has bulged sufficiently to bring its surface up to the general level, or else a central depression has been filled by growth and capped by turf.

The writer's observations were insufficient to disclose the factors which control the character of block development. The "elevated blocks" are characteristic of drained areas and are nearly constant features near banks. The "depressed blocks" are associated in the writer's mind with flat, marshy country. This, however, may be the effect rather than the cause of the difference in character of the blocks. The network of depressions drains the elevated blocks, but the ridges form dams which interfere with surface drainage.

As the growing vein of ice becomes more wedge-like in form, the pressure exerts a vertical component against the sides of the wedge. This tends to force the wedge upward. If an upward movement should occur, the ice would carry its protective covering with it and be able to exist level with or even somewhat above the general surface of the block. Since a bulging of the block by the growing wedge seems necessary, some upward motion of the wedge may have taken place without bringing the top of the wedge up to the

FIG. 15.—Photograph of exposure shown in Fig. 14

general level. In the depressed blocks it is to be noticed (Figs. 7 and 8) that the surface of the ground between the parallel ridges (probably underlain by ice) is higher than that of the blocks on either side. No exposures were found illustrating this case, so it is impossible to say whether the surface of the ice is actually higher than that of the blocks.

The usual covering for the ice is muck capped by turf, or peat capped by growing sphagnum (?) moss. As the thickness of this mantle increases by surface growth, the limit of the summer's thawing should rise, thus allowing a constant upward extension of the surface of the ice wedge at the locus of growth. Only two or three cases of apparent upward growth of the surface were seen. In one

case (Fig. 9) there is an upward projection of ice above the general surface of the wedge, indicating a sudden change of the limit of thawing. The others showed a dome-shaped surface, indicating a gradual change. Since the majority of exposures show the surface of the wedges to be nearly parallel with the surface of the ground,

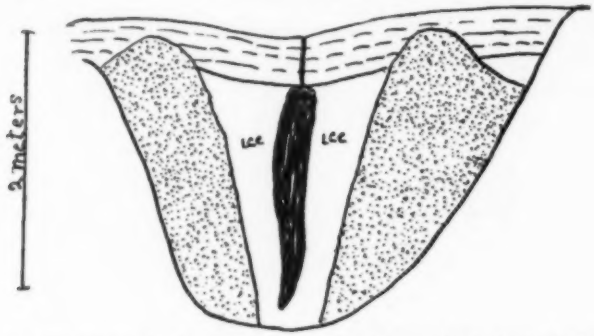

FIG. 16.—An ice wedge in sand. A tunnel has been cut in the ice by drainage of surface waters through the frost crack. The sand on either side is apparently bulged.

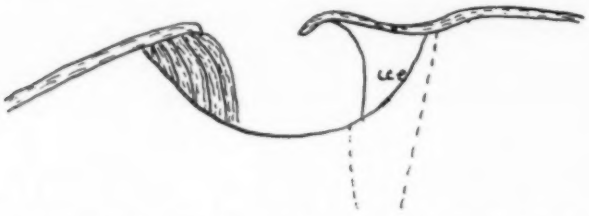

FIG. 17.—Section perpendicular to a bank, showing upturned muck beds in a tundra block which has broken off along an ice wedge.

it seems that a balance must be maintained between the thickness of the covering and the increase in area to be covered, as the wedge becomes wider.

The rate of growth of turf must be very slow in this region, for there are many half-buried bowlders on the surface of the tundra, which have been there since glacial times, or at least since the coastal plain emerged from the sea. Many bare spots exist where the turf has not been able to get a footing.

Where the protective covering is of muck, creeping of the soil will tend to close up the open frost crack. This will thin the covering, and if the rate of surface growth is not sufficient to counteract the resulting decrease in thickness, the upper surface of the ice will be lowered by melting. The increased slopes will cause side material to creep down over the ice, thus keeping the protective mantle up to the required thickness. A shallow depression will thus be formed whose slopes are of the proper angle to cause the proper amount of creeping.

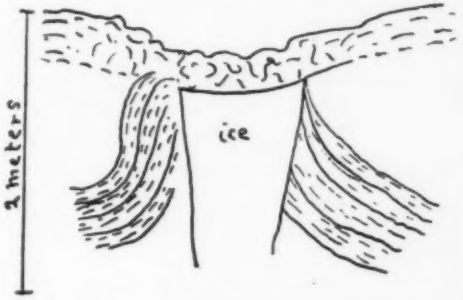

FIG. 18.—An ice wedge in muck showing upturned strata

In the case of sphagnum (?) moss the case may be somewhat similar. The moss and subjacent peat may also close the crack by creeping. At the same time the bed will become thinner, but growth of the moss will soon thicken it again. If the moss grows too fast, the depression will be filled and the conditions of moisture favorable to growth will cease. Thus it is possible for the growing ice wedge to have a covering of peat of constant thickness.

When a bank is undercut by wave or river action, large masses of tundra often break off. Since the ice wedges are planes of weakness, the break is along the edges of the polygon blocks, whenever this is possible. This is especially true of high banks, where whole blocks will break out, leaving many re-entrant angles in the resultant bank, along which a nearly continuous exposure of ice may be seen. The impression is carried away of a heavy horizontal sheet

of ice of great thickness, whereas, in fact, little of it extends back more than a few feet from the face of the exposure (Figs. 19, 20, and 21).

In Fig. 22 is shown a plane-table map of an area of frost cracks, and a sketch of the exposures of ground-ice in the bank immediately below. The polygon blocks were of the elevated type, but the relief was very faint, being somewhat obscured by sand which had drifted up from a sand spit on the left. The exposure was somewhat slumped, but gave sufficient details to illustrate the case.

FIG. 19.—Exposure of ice extending some distance inland. A tundra block is breaking off along an ice wedge.

The heavy lines on the map show open frost cracks; the dotted lines, the evident loci of cracks. Where there was no surface indication, no lines were drawn. The shaded areas are supposedly underlain by ice wedges.

Ground-ice occurs at the intersection of every crack with the bank, where the details were not masked by slumping.

The average diameter of eleven blocks shown on the map is about 11 meters. The largest block is about 11 by 15 meters, and the smallest 5 by 8 meters. The largest wedges of ice are about 2.5 meters wide at the top, and this width has been used in indicating the areas probably underlain by ice, except where surface

indications pointed to new loci. About 20 per cent of the tundra is found to be probably underlain by ice of greater or less thickness.

On a 250-mile boat trip from Flaxman Island to Point Barrow in the summer of 1914, good exposures of muck banks always revealed ice. Many miles were examined closely on foot or from the boat, and very little ice was observed which was not definitely in the form of vertical wedges associated with frost cracks on the surface of the tundra.

FIG. 20.—Tundra block broken off. Ice wedge at left

Ground-ice wedges with their accompanying surface features are typically associated with muck formations, and none were seen elsewhere. River silts, elevated sand and gravel deposits, and soft shales have been carefully examined and the only ice found in such places was evidently of another form and of a different origin. Straight lines leading across the gentle surface undulations of sand spits have frequently been observed, and they could be explained only by frost cracks. No polygonal forms have been seen in such places. The writer is unable to say whether ice wedges develop in such sands, for the exposures made by fresh wave-cutting are seldom more than 2 or 3 feet deep, which is less than the depth reached by the summer's thawing.

RATE OF GROWTH OF WEDGES

Fresh ice-filled cracks 8–10 mm. wide have been observed in the ground immediately above the ice wedges. This may be put as the maximum width of the crack. Open cracks about 5 mm. wide have been found in the ice itself near the upper surface. The width, of course, diminishes downward. If 5 mm. is assumed as the width at the top, it would require only 600 years to build up a wedge 3 meters wide, which is about the maximum width seen in the region.

FIG. 21.—A large tundra mass broken off along the sides of a polygon block. The ice has mostly melted away.

If the cracks do not all open every winter, this period must be multiplied by some factor. The writer had frequently observed open cracks during the previous years, but not realizing their bearing, did not keep any record of their abundance. About 1,000 years seems to be the order of age of the largest wedges. Unless some unknown cause prevents a greater growth, the temperature could not have been sufficiently low to bring them into existence at an earlier date, or else the coastal plain has not been elevated above sea-level for a longer period.

If we assume that the elevated blocks are bulged by the growing ice, the amount of general elevation of the surface of the tundra can

readily be calculated. If 20 per cent is taken for the surface compression of the block, the average compression will be 10 per cent. An average block 11 meters in diameter will be compressed horizontally 1.1 meters to an assumed depth of from 8 to 10 meters. This will cause an increase in a vertical direction of about 1 meter.

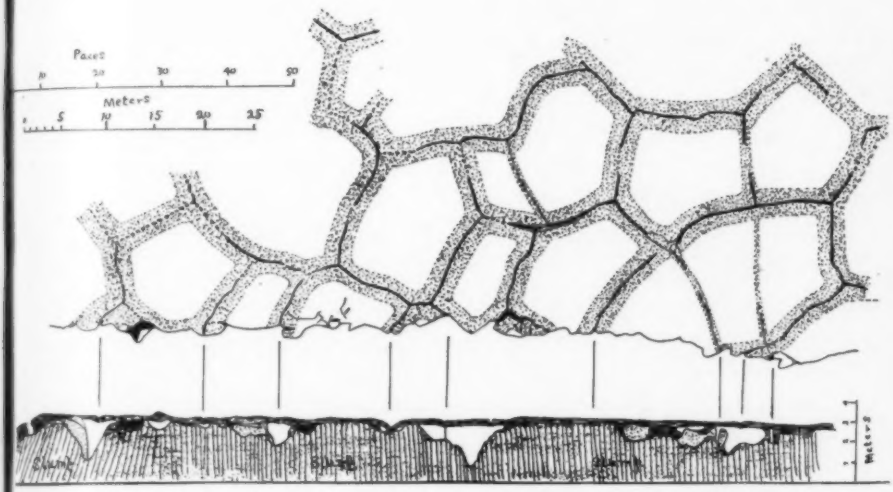

FIG. 22.—Planetable map of frost cracks on the tundra, with a sketch of the exposures of ground-ice in the bank at one edge of the mapped area.

The heavy lines on the map represent open frost cracks in July. The dotted lines indicate evident frost-crack loci. The stipple marks show the areas probably underlain by ground-ice.

In the section below the map, the white spaces represent ground-ice, the dotted spaces, sand. The rest of the exposure has slumped.

The case is different with the depressed blocks, where the adjustment is concentrated into the ridges that surround them. The depressions are being continually filled with growing vegetation, as well as picking up wind-blown material, thus forming muck beds. In this way a much greater general elevation of the surface of the tundra is possible. Much of the muck of the region may have been developed in this way.

The principle of the development of ground-ice wedges is capable of widespread action throughout the region of permanently frozen ground. It is so persistent on the north shore of Alaska that it is to be expected to come into play in similar regions elsewhere. The writer is inclined to believe that much of the ground-ice described in the literature as in horizontal sheets may turn out to be in vertical wedges. In the classical locality at Eschscholtz Bay, no one observer agrees with the others. One says that there is a solid mountain of ice, while a second finds only a thin veneer of ice against the face of the bank. A more careful observer finds scattered outcrops of ice, including at least one vertical dike. In other regions "polygon marks" and vertical markings upon whitish ice are mentioned.

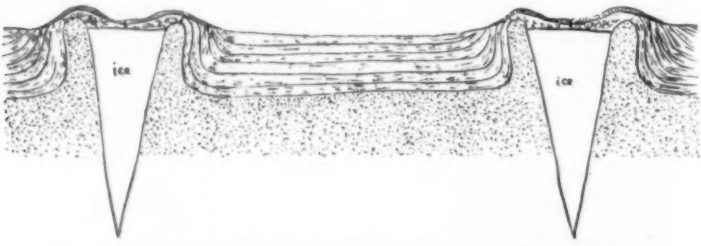

FIG. 23.—Hypothetical section of ice wedges and depressed polygon block

SUMMARY

The permanently frozen ground contracts in the cold Arctic winter and cracks are formed, which divide the surface of the ground into polygonal blocks. In the spring these frost cracks become filled with surface water which immediately freezes. In the expansion of the frozen ground as its temperature rises in summer, the vein of ice being more rigid than the country formation, the readjustment takes place in the latter. The result is to bulge up the inclosed block either bodily or else locally along the sides of the ice. During the next winter's cold wave, a new crack forms at the same locus, so that a continually growing wedge of ground-ice is formed (Fig. 23). Thus the tundra becomes underlain by a network of ice wedges, which inclose bodies of the original formation.

STRATIGRAPHY OF THE WAVERLY FORMATIONS OF CENTRAL AND SOUTHERN OHIO[1]

JESSE E. HYDE
Western Reserve University

PART I

CLASSIFICATION
BEDFORD AND BEREA FORMATIONS
SUNBURY SHALE
CUYAHOGA FORMATION
The Facies
The Toboso Conglomerate Facies
Extent and Thickness
The Black Hand Member
The Berne Member
Origin of the Conglomerates
The Hocking Valley Conglomerate Facies
Extent and Thickness
The Lithopolis Member
The Fairfield Member
The Black Hand Member
The Berne Member
The Granville Shale Facies
Extent and Thickness
The Black Hand Member
The Raccoon Member
The Berne Member

PART II

The Scioto Valley Shale Facies
Extent and Thickness
Members
The Vanceburg Sandstone Facies
Extent and General Nature
The Henley Member
The Buena Vista Member
The Rarden Member
The Vanceburg Member
The Churn Creek Member

[1] Published by permission of the State Geologist of Ohio.

The Cuyahoga Formation in Kentucky
Paleogeography of the Cuyahoga
The Toboso and Hocking Valley Conglomerate Areas
The Vanceburg Sandstone Facies
The Source of the Material
LOGAN FORMATION
Subdivisions and extent
The Byer Member
The Allensville Member
The Vinton Member

PART I

CLASSIFICATION

The following columns of formations (Table I) in as many different regions are presented chiefly to indicate the members composing the Cuyahoga in its different facies. To these have been added the other formations with some duplication of names so that the columns are somewhat more than a classification; they are a partial correlation table. The top of the Cuyahoga on the Ohio River, as explained later, is the stratigraphic equivalent of the lowest part of the Byer member farther east and north. The amount of equivalency cannot be exactly indicated.

The names Vinton, Allensville, Byer, Berne, Fairfield, Lithopolis, Churn Creek, Vanceburg, Rarden, Henley, and Portsmouth are new formational names,[1] and the name Buena Vista is applied somewhat differently from its original usage but not with a wholly new meaning. The name Raccoon is adopted from Hicks.[2]

In presenting a summary of the findings of several years' work in this field it is impossible to cite any but the chief facts. The presentation of the large body of evidence on which these conclusions rest, soundly it is believed, must await the completion of the work now being prosecuted on the faunas of the region. Such

[1] The names Vinton, Allensville, and Byer were first used without definition in a chapter by the writer entitled, "The Geological History of Fairfield County, Ohio," in the *History of Fairfield County*, pp. 203–23 (Chicago: Richmond-Arnold Publishing Co., April 15, 1912). The names were applied to the respective members in Fairfield County but they were not defined. They are here defined for the first time.

[2] L. E. Hicks, *Am. Jour. Sci.*, 3d. Ser., XVI (1878), 216.

TABLE I

Central Fairfield and Hocking Counties		Central Licking County		Eastern Licking County	
Logan formation	Vinton member Allensville member Byer member Berne member	Logan formation	Vinton member Allensville member Byer member Berne member	Logan formation	Vinton member Allensville member Byer member Berne member
Cuyahoga formation, Hocking Valley conglomerate facies	Black Hand member Fairfield member Lithopolis member	Cuyahoga formation, Granville shale facies	Black Hand member Raccoon shales, top only seen, rest known from wells	Cuyahoga formation, Toboso conglomerate facies	Black Hand member "Sandstones" (wells) "Shales" (wells)
Sunbury shale Berea Grit Bedford formation		Sunbury shale (wells) Berea Grit (wells) Bedford formation (wells)		Sunbury shale (wells) Berea Grit (wells) Bedford formation (wells)	

Southwestern Scioto County		Central Ross, Pike, and Scioto Counties	
Logan formation not subdivided		Logan formation not subdivided	
Cuyahoga formation, Vanceburg sandstone facies	Churn Creek member Vanceburg member Rarden member Buena Vista member Henley member	Cuyahoga formation, Scioto Valley shale facies	Portsmouth member Buena Vista member Henley member
Sunbury shale Berea Grit Bedford formation		Sunbury shale Berea Grit Bedford formation	

relationships as would necessitate even brief discussion of facts for and against alternate interpretations have been passed over.

It is obviously impossible even to mention the results obtained by many previous workers who have contributed, often fundamentally, to the subject. The stratigraphy of the upper part of the Waverly had been studied in detail in a single small region only, in central and eastern Licking County, near the center of the state, and at the northern end of the area herein considered. Hicks in 1878 gave a brief description of the formations of this limited region and Herrick in the eighties described other subdivisions, particularly with reference to the faunas. Prosser[1] in 1901 reviewed the work of previous writers on the stratigraphy, adopted the subdivisions made by Hicks and Herrick, applied to them the proper geographical names, and described in detail some of the sections in the region. Prosser's description of the sections at Newark, subdivided after Hicks and Herrick, is the one generally quoted in more or less detail as representing these formations in Ohio.

It is not surprising to find that, as a result of the changed perspective afforded by detailed work over a much wider area, the subdivisions adopted by Prosser in this section must be revised. In fact, both Hicks and Herrick failed to correlate correctly the members across this small area in Licking County which they studied in some detail. In addition, it appears that one member, described as a formation, the Black Hand, is not as important stratigraphically as some members that were not particularly distinguished by the earlier workers.

In Table II are given the subdivisions of the Newark section as stated by Prosser, and in a parallel column the ones herein adopted for the same section. This will serve to show the extent to which the interpretation of the section has been altered.

It will be noted that the names Cuyahoga and Logan are retained for two chief terranes, and these are extensively subdivided into members. These have been recognized as two chief terranes of

[1] *Jour. Geol.*, IX (1901), 205–31. The Quarry Run section is described on pp. 221–26. Other outcrops seen later led to a second description of this section with certain changes in interpretation. This was published in 1904, *American Geologist*, XXXIV, 358–61.

the Waverly for forty years. When the errors of interpretation and correlation of various geologists during this length of time are resolved out, it is peculiar that, after all the different applications that have been made of these names, it should now fall to them to denote precisely the same beds that they were originally applied to forty years ago, or, as nearly as can be determined, the central Ohio equivalents of these beds. The subdivisions of the Logan here adopted constitute exactly the Logan formation at Logan, the locality from which E. B. Andrews named it in 1870, since when the

TABLE II

Proposed Classification		Prosser	
			Logan formation
Logan formation	Vinton member		
	Allensville member	Conglomerate II	Black Hand formation
		Allerisma shale	
	Byer member		
Cuyahoga formation	Berne member	Conglomerate I	
	Black Hand member		
	Raccoon shales, only a few feet exposed		Cuyahoga formation

name Logan has been used with precisely the same meaning by no other writer. The Cuyahoga was named from outcrops on the Cuyahoga River in northern Ohio where it is overlain by the Pennsylvanian, the whole of the Logan and some of the Cuyahoga having been removed by pre-Pennsylvanian erosion. It is not, at present, possible to demonstrate that the beds to which the name Cuyahoga is here applied are the precise equivalent of the beds in the type section; but it is now evident that they are almost or quite identical with those shales in the shale facies in central Ohio which Orton knew lay between the Berea Grit and the Logan, which he called Cuyahoga, but of which he never fixed the precise limits.

This does not imply that any of these workers understood the true relationships. They did not; none of them knew that the Black Hand (or Waverly conglomerate as it was called) and the underlying coarse sandstones (which indeed were practically

unknown) are merely a facies of the Cuyahoga, and the attempts, particularly by Orton, properly to place these conglomerates in the Waverly column led to confusion. He included the Black Hand with Andrew's Logan under the term Logan Group, a procedure that has been followed by many.

Yet, in spite of the fact that these names are now made to denote the same beds that they denoted in the earliest usage in central Ohio, a question may be raised by some whether they should be retained; whether it is established that these subdivisions are two chief subdivisions, and that a classification which would drop one or both terms and place some of the members here proposed in a higher rank would not more nearly indicate the true relations. Prosser in his work in northeastern Ohio has dropped the term Cuyahoga[1] and builds this portion of his Waverly column out of members which were formerly units within the Cuyahoga. From this it would appear that he does not regard the Cuyahoga shale, as delimited by Newberry in northern Ohio, as a terrane of established stratigraphic significance.

Apropos of this question it may be remarked that in the present work it has been found exceedingly convenient to retain both. The classification of the Cuyahoga of central and southern Ohio here proposed with its numerous members in different facies is very complex; nevertheless, when the entire area is considered, it appears that these groups of members constitute a distinct terrane, for no one of its members in any facies can be satisfactorily discussed except in connection with the other members of that facies. Furthermore, the Berne member, whether it be regarded as closing the Cuyahoga or opening the Logan, separates two groups of sediments that are essentially different from each other in many ways. The retention of the term Logan is necessary, for although easily subdivided into three important members over most of this area, along its southwestern margin it is not so divisible and one name is needed to denote sediments that are there the equivalent

[1] "The Devonian and Mississippian Formations of Northeastern Ohio"; *Geol. Surv. Ohio*, 4th ser., *Bull. 15* (1912), 574 pp.

of all three a few miles to the eastward. It is true, as will be pointed out, that on the Ohio River the lower part of the Logan sandstones pass into shales that are, so far, indistinguishable from the upper part of the Cuyahoga and are included in the upper part of the Cuyahoga. Nevertheless, for the reasons just stated, the conceptions of Logan and Cuyahoga are exceedingly convenient ones, whatever may be their actual stratigraphic importance to be determined later. Final decision should be reserved until the evidence of the faunas can be presented.

Perhaps the greatest innovation from the Waverly column as heretofore established is the reduction in rank of the Black Hand formation. This had come to be regarded as a distinct formation between the Cuyahoga and Logan, a stratigraphic unit that had to be considered in any attempt at correlation of rocks of this general age. It is, however, a local development of the Cuyahoga and is, apparently, not as important a stratigraphic unit as any one of the three members of the Logan.

BEDFORD AND BEREA FORMATIONS

In the classification of the Waverly formations here presented, the Bedford formation has been included. By such inclusion it is not intended to express any opinion in the discussion now being waged as to whether this formation should be placed in the Devonian or should be retained in the Waverly as was the practice for many years; it is here retained largely because such has been the practice. The present discussion does not attempt to correlate this or other subdivisions of the Waverly with the standard time scale because that would involve discussion of the faunas, a subject not yet ready for presentation. An earlier paper by Hyde on a special phase of the Bedford and Berea gives their general character in southern Ohio although by no means a summary of the various problems connected with them.[1]

One feature there mentioned should be emphasized. Since that paper was published several papers have appeared describing the unconformity between the Bedford and the Berea in northern and

[1] *Jour. Geol.*, XIX (1911), 257–69.

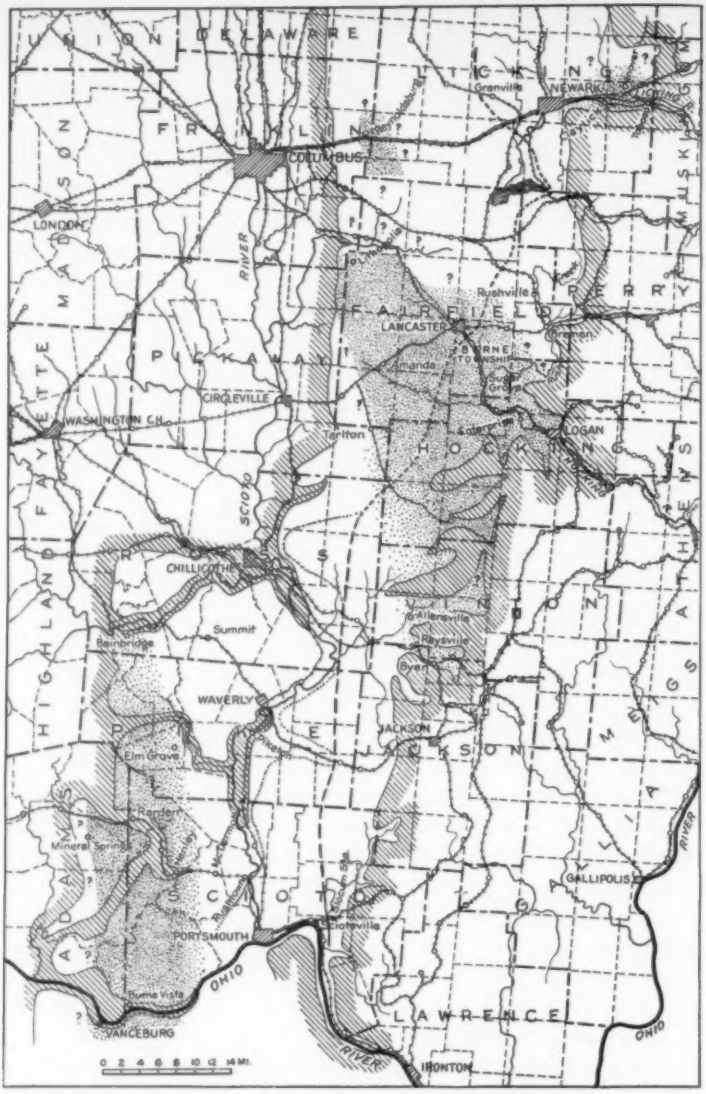

FIG. 1.—A. Map showing outcrop belt of Waverly formations of central and southern Ohio, bounded on the western side by Devonian and Silurian rocks, on the eastern side by the Pennsylvanian. These boundaries are drawn only approximately and are generalized. The conglomerate and sandstone facies of the Cuyahoga are stippled, at the northward the Toboso conglomerate area, near the central portion the Hocking Valley conglomerate facies, and in the southwestern part the Vanceburg facies; intervening are the Granville and Scioto Valley shale facies. Question marks indicate uncertainty due to removal by erosion, burial beneath glacial deposits, or unobserved areas. The known western margin of the Allensville member of the Logan is represented by a line east of the center of the Waverly belt. Near the Ohio River its actual stratigraphic western limit is represented by a continuous line. From there northward to Hocking County its known westernmost occurrences are represented by coarse dashes—the horizon occurs possibly as far west as the dotted line and its disappearance westward is known in northern Scioto County, but the precise zone of disappearance is not located. From Hocking County northward it extends as far west as the westernmost outcrops of its horizon, represented by short dashes.

central Ohio.[1] In view of the debated age of the Bedford, such an unconformity, if widespread, would be urged, and indeed it has already been suggested by Prosser,[2] Girty[3] and Burroughs[4] as evidence for the separation of the Bedford from the remainder of the Waverly and of its affiliation with the Devonian. It is therefore important to emphasize that there is no evidence seen by the writer south of Lithopolis in Fairfield County of the existence of any such plane of unconformity. There is irregularity at the plane which in some sections appears to be this contact, but apparently of the same kind and of no more importance than many other similarly irregular bedding planes, often in the same section, and not of a nature, so far as observed by the writer, to warrant description as evidence of erosion. On the other hand, at many localities, there is a gradation from the Bedford to the Berea, sometimes abrupt, elsewhere gradual. The Berea of southern Ohio is only a phase of the Bedford; they consist of precisely the same kind of sediments with the same ripple-marked structure, a sedimentary structure so peculiar and unusual that its occurrence in both Bedford and Berea cannot be urged as an insignificant coincidence by anyone at all familiar with sandstone formations and their structures. Almost the only distinguishing feature between them is that the sandstone beds are

FIG. 1.—B. This outline map is a guide map to indicate the position in Ohio of the area mapped in the large one.

[1] W. G. Burroughs, "The Unconformity between the Bedford and Berea Formations of Northern Ohio," *Jour. Geol.*, XIX (1911), 655–59; C. S. Prosser, "The Disconformity between the Bedford and Berea Formations in Central Ohio," *ibid.*, XX (1912), 585–604; C. S. Prosser, "The Devonian and Mississippian Formations of Northeastern Ohio," *Geol. Surv. Ohio*, 4th ser., *Bull. 15* (1912); W. G. Burroughs, *Economic Geol.*, VIII (1913), 480–81; "Berea Sandstone in Eroded Cleveland Shale", *Jour. Geol.*, XXII (1914), 766–71.

[2] C. S. Prosser, *Geol. Surv. Ohio*, 4th ser., *Bull. 15* (1912), 511, 512.

[3] George H. Girty, "Geological Age of the Bedford Shale of Ohio," *Annals New York Acad. Sci.*, XXII (1912), 296.

[4] *Jour. Geol.*, XXII, (1914), 771.

relatively thicker and the shales relatively thinner in the Berea, and some, not all, of the sandstones of the Bedford are slightly calcareous, never enough so to be called an impure limestone. Furthermore, the same structure in the Berea sandstone generally in central Ohio and at the only one of the localities seen by the writer, Lithopolis, where the unconformity is present, shows that the Berea above the unconformity in central Ohio is of much the same type as, and is at least closely related to, the Berea of southern Ohio, and presumably is not widely different from it in age.

SUNBURY SHALE

The Sunbury shale is a thin bed of black, fissile shale present over the entire area here considered, either on outcrop or under cover. Of it no more need be said in view of Prosser's excellent description of its features,[1] except that it with the subjacent Berea has been invaluable as a base from which to pursue work in the complex overlying formations.

CUYAHOGA FORMATION

THE FACIES

The Cuyahoga formation has for years been described as a shale formation. It is true that sandstone members, sometimes of great economic importance, have been known to occur in it at various points, and thin sandstones in greater or less abundance have always been recognized as a component throughout its thickness. However, the descriptions which have appeared in print have generally been such as to give the impression that it is largely a body of shales and not a great deal more complicated than the formations below it. This is owing to the fact that portions of the massive sandstone and conglomerate facies were not recognized as Cuyahoga but were considered a distinct horizon, the Black Hand formation, or, under the name Logan conglomerate, were considered a part of the overlying Logan formation, while the remaining portions of these same sandstones were practically unknown.

The Cuyahoga formation may be made up very largely of shales in one area but of sandstones or conglomerates in adjacent areas

[1] *Jour. Geol.*, X (1902), 262–312.

at no great distance. Furthermore, in any such area, the sediments are likely to remain much the same from the bottom of the formation to its top. That is, in a sandstone or conglomerate area we may expect to find sandstones or conglomerates or sandy shales more or less continuously throughout the formation, and in a shale area the sandstones are likely to be thin or inconspicuous. This is due to localized conditions of sedimentation which prevailed during Cuyahoga time. The result is that distinct depositional facies can be recognized with pronounced uniformity in the lithology of the vertical column in any one area, except in the regions of transition from one facies to the adjacent one.

It is necessary to recognize five such facies. Beginning in Licking County and passing southward across the outcrop (see outline map), these are (1) the *Toboso facies*, an area in which the sediments are largely non-fossiliferous conglomerates and sandstones with shales in the lower part; (2) the *Granville facies*, mostly shales with finer-grained fossiliferous sandstones in the upper part, conglomerates absent or limited to a few thin beds; (3) *Hocking Valley conglomerate facies*, mostly conglomerates and coarse sandstones with some shale, fossils wanting; (4) *Scioto Valley shale facies*, argillaceous shales with thin sandstone beds tongued into them from the provinces on either side, fossiliferous; (5) the *Vanceburg sandstone facies*, an area in which are developed sparingly fossiliferous sandstones of a different type from those in the conglomerate areas.

Within these facies, the Cuyahoga is composed of distinct lithological members, which can be traced in regular succession over much or all of the facies and sometimes into the adjacent facies. It is these relationships that have given rise to the complex classification here presented.

There is also to be noticed, before taking up the facies in detail, the fact that they all have a pronounced axial trend from north-northwest to south-southeast, and that this axial trend does not correspond to the direction either of the strike or of the dip of the series, but is intermediate between them. As a result the area of any one of these facies extends diagonally across the outcrop belt of the Cuyahoga.

The northern limit of the present work in Licking County is by no means a logical one; it cuts through the heart of the Toboso conglomerate facies. Besides, conglomerate areas have been reported from Knox County to the northward which may be at about the same horizon and in which certain structures are reported which are also found in the Toboso and Hocking Valley provinces.[1] This conglomerate may be at a higher horizon, as its base appears to be about 965 feet above the base of the Bedford shale. Whether they are a continuation of the conglomerates of the Toboso province or whether they belong to a distinct facies is not certainly known, but apparently they are distinct. Other conglomerates of a yet more uncertain horizon are reported from yet farther north in the northeastern part of Richland County,[2] southern Ashland,[3] and in Wayne County[4] where G. F. Lamb describes two conglomerate horizons.

The two conglomerate areas considered in this paper, the Toboso and Hocking Valley, have much in common. Lithologically and in the structure of their beds they are very closely related, and both have clearly been formed in much the same way. The other sandstone facies, the Vanceburg, is wholly different in these and in other respects. Furthermore, the Granville shale facies lying between the two conglomerate areas, although lying mostly below drainage and hence inaccessible except by well-records, is clearly influenced largely by their proximity. The Black Hand and Berne members lying at the top of the Cuyahoga in the conglomerate areas possibly in places under cover extend entirely across the Granville facies, although the former in part passes into shale in its surface outcrops. In fact, it seems very probable that the Toboso and Hocking Valley conglomerate areas are merely lobes extending northwestward from a much larger conglomerate area lying under cover of the Coal Measures at no great distance to the southeastward, and that the Granville shale province is the accumulation of shales with considerable sandstone lying between these lobes. The Scioto shale facies is not influenced to nearly such an extent by the adjacent sandstone areas.

[1] *Geol. Surv. Ohio*, III, 337, 338. [2] *Ibid.*, pp. 317–18. [3] *Ibid.*, p. 523.
[4] *Ibid.*, p. 539; also G. F. Lamb, *Ohio Naturalist*, XIV (1914), 344–46.

THE TOBOSO CONGLOMERATE FACIES

Extent and thickness.—The conglomerates of this facies are exposed typically in the east-central part of Licking County. The areal extent is unknown to the writer, since it has not been traced to the northward, and observation has been confined to the excellent outcrops seen within two or three square miles in the vicinity of the post-glacial gorge of the Licking near Toboso and Hanover. It seems very likely that it is small and not at all comparable with the great Hocking Valley area. The entire observable width is less than three miles, since the Black Hand passes below drainage immediately east of Toboso, as a result of regional dip to the eastward.

The thickness of the Cuyahoga in this area is about 588 feet (gas well at Everett glass-sand plant above Toboso where the upper 340 feet are reported as "sandstone," the remainder as "shale"). Of this, only the topmost 100 feet are exposed above drainage. It was to this exposed 100 feet of conglomerate in the gorge of the Licking that Hicks gave the name Black Hand, from Black Hand Rock near Toboso. From the original Black Hand of Hicks, the topmost foot or two are now separated by the writer as the Berne member.

The Black Hand member.—This member of the Toboso facies is a massive, coarse quartz sandstone with abundant quartz pebbles which are seldom over an inch in diameter and usually half an inch or less. It is pure enough to be used for glass sand after washing. The color is usually yellow or buff, sometimes reddish. Fossils, worm trails excepted, have not been recorded.

The structure of this member is of significance. The sandstones within 10 or 15 feet of its top lie horizontally or nearly so. Below this the bedding of the remainder of the exposed portion, 55 or 60 feet, is inclined, in general, to the northward at angles of from 5° to 15°, 10° being usual. On the western side of the area, that is, near and to the southward of Hanover, the dips are slightly northwest, the strikes ranging from due east and west to N. 80° E. Farther east, and observed especially on the Licking River, the dips swing to east of north, the strikes ranging from N. 80° W. to N. 50° W. This difference in the dips on the east and west sides of

the area within short distances suggests strongly that this conglomerate mass is not one of great extent, and that the more easterly outcrops are really on the eastern side of the conglomerate area. That these are true beds is shown by the occasional occurrence of ripples on their upper surfaces or of a very thin parting of clay shale between two inclined sandstone beds. Such a feature may be found along a bedding-plane from the point of its emergence near stream level to its disappearance near the top of the inclined beds.

Although the inclination of the larger beds of the region is quite regular, the structure within these beds presents the greatest diversity. The material is very coarse sand with abundant pebbles, and evidence of strong current action is seen. Cross-bedding is everywhere present in the inclined portions. These minor structures follow no appreciable order. The cross-bedding is in any direction. It may be in opposite directions in superjacent beds and often is inclined directly against the slope of the larger beds, contradictory as it may seem. Erosion planes are abundant; although local and limited in extent, these are true local erosion planes which can frequently be traced for many yards along an outcrop, and appear to be distinct from the small cuttings which are always found where there is evidence of current action and which are usually referred to simply as cross-bedding. To the eastward the Black Hand goes under cover with these structures yet present, but on the western side of the conglomerate area the bedding gradually flattens out and the current structures and cross-bedding disappear together with the pebbles, so that within a mile or two the member becomes a more or less structureless (except for ordinary bedding-planes), coarse sandstone. This is the way it occurs at Clay Lick only two and one-half miles west of where the structures are at their maximum of development. And only a short distance west of Clay Lick, thin clay shales begin to appear below the massive upper 100 feet or Black Hand member. These suggest that the Granville shale province is being approached and also fairly well demonstrated that the upper 100 feet more or less of sandstones in the Toboso province constitute a member distinct from the sandstones below it reported in the well.

Hicks[1] noticed the general northerly dip of these beds and the oblique lamination dipping in all directions and considered it the structure of a sea beach. No worker since has paid any attention to this acute observation or its significance, and Herrick derived the material from the northeast, flatly contrary to the evidence of the structure.[2]

The Berne member.—At the top of the conglomerates is found, at all points, one or two feet of coarser, more pebbly conglomerate. This is designated the Berne member. Its discussion is reserved to the consideration of the Hocking Valley conglomerate area.

Origin of the conglomerates.—It is evident that the sandstones and conglomerates of this area were derived from the south-southeastward. It is true that only the upper sixth of the thickness is exposed, but it appears, from the structures observed in the Hocking Valley conglomerate area, that the statement may safely be applied to the entire thickness. It appears that the visible portion of the conglomerates at least were built forward by currents of considerable strength, either as a sand-spit, as was suggested by Hicks, or delta-wise. The dips are low, far below the angle of repose for subaquatic accumulation of such materials, and this, together with the exceedingly irregular cross-bedding within the inclined beds, suggests that the material must have been in part distributed by submarine currents.

THE HOCKING VALLEY CONGLOMERATE FACIES

Extent and thickness.—The conglomerate area traversed by the Hocking Valley has been the more closely studied. It lies far enough west on the outcrop belt that the most of its structure can be observed, whereas the Toboso area lies so near the eastern margin of the Waverly belt that only the upper 100 feet of the Cuyahoga are shown.

This area occupies the central and western parts of Fairfield and the western half of Hocking counties, barely extending into Vinton County. The southwestern part of Licking and the eastern margin of Franklin should also be assigned to it. Along its western

[1] *Am. Jour. Sci.*, 3d ser., XVI (1878), 217.

[2] *Bull Sci. Lab. Dennison Univ.*, II, Part 1 (1887), 9, 10.

margin it has a length of 45 or 50 miles, its maximum width is about 20 miles. In the southeastern and eastern portions only the upper beds are exposed; in the western and northwestern portions only the lower part remains. The entire thickness is not exhibited in any one section. However, well-records have been easily obtained from the Sugar Grove gas field which extends across it, and have been of much service in unraveling the structure, although little more than generalized impressions can be obtained from the reports coming from the heavy drills there used.

The sandstones of this province are developed along a very distinct axis which trends north-northwest, south-southeast. Along this line of maximum sandstone development, the thickness is 625 feet, decidedly greater than in the Granville shale province to the eastward, and more than twice as thick as it is some miles to the southwestward in the Scioto Valley shale facies where it is about 295 feet. This increased thickness is due to the increased amount of coarse material.

Four members are recognized in the Cuyahoga of this area.

The Lithopolis member is best exposed in the northwestern part of Fairfield County in the vicinity of Lithopolis. The name is newly proposed. It is a series of *thin, horizontal, interbedded sandstones and shales*. The fact that they are horizontal is to be emphasized. The sandstones are usually light gray or bluish in color, moderately fine grained, and evenly bedded. The beds are usually several inches and sometimes two or three feet thick. The shales are argillaceous, and usually, but not always, somewhat sandy; they are commonly gray in color. Carbonaceous material may be present at times sufficient to darken the gray. The sandstones and shales, on the whole, are about equal in amount, although at various horizons one may dominate the other and the sandstones appear to be considerably in excess in the upper part.

The thickness varies from 118 feet to at least 140 feet and possibly 180 or 200 feet between Lithopolis and Chestnut Ridge two miles to the eastward. It is overlain at these localities by a massive coarse, yellow sandstone which is wholly different from those of the Lithopolis member. To the southward, beneath the central portion of the Hocking Valley province, the Lithopolis

member is entirely below drainage but the well-drillers invariably report from 100 to 200 feet or even more of "shale" at the base of the Cuyahoga. This appears to be largely the Lithopolis member, but the records of drillers are usually difficult to interpret, and it does not follow that the entire "shale" bed reported is Lithopolis. The fact that it is reported as shale also need not be disconcerting, as a series more than half made up of sandstone might be so reported. Nor is the reported variation in thickness necessarily a fact; this interval is never measured by the drillers and is almost always given from memory.

Prosser and Cumings have described the Lithopolis occurrences in minute detail and also similar strata from the lower part of the Cuyahoga in eastern Franklin and western Licking[1] counties. Those of the two last localities have not been examined by the writer, but they appear to be of exactly the same type as those at Lithopolis. They have separated off the lower 50 feet of the beds here called Lithopolis and correlated them with the Buena Vista member, or lower 50 feet of the Cuyahoga according to Orton. Since there is no member in central or southern Ohio so limited which is of any significance, stratigraphic or otherwise, the name Buena Vista has been limited in the present work to the principal quarry stone at Buena Vista in the Vanceburg facies from which it was originally derived, and its stratigraphic equivalent cannot as yet be detected and indeed is probably not recognizable in the Hocking Valley conglomerate area. The stratigraphic horizon of the Buena Vista member, as hereinafter defined, will fall in the Hocking Valley facies at least as high as the middle of the Cuyahoga and possibly higher.

The Fairfield member is a series of alternating sandstone and shale beds which quite frequently show initial dips to the northward of two to six degrees. The sandstones when typically developed are coarse, reddish yellow, brown, or bluish gray, sometimes pebbly, and quite commonly are found in massive members 20–60 feet thick with intervening shaly members of similar thickness. The shale strata, however, are themselves formed of thin interbedded sandstones and shales, the former likely to be very coarse,

[1] *Am. Geol.*, XXXIV (1904), 335–58.

even when thin. The features which characterize the member are the *alternating coarse sandstones and shale, the former often massive and thick*, and the *low initial dips*. At some localities there are no shales and the bedding is not always inclined. The last seems particularly true in the northern part of the area. The member ranges from 200 to 330 feet in thickness, but exact figures are impossible.

The Black Hand member is the principal cliff-forming member of the Cuyahoga, and the beautiful scenery of Fairfield and Hocking counties is chiefly the result of its resistance to erosion. It is a massive coarse sandstone or conglomerate and is distinguished from the underlying Fairfield member by the *absence of shale* (very rarely single beds an inch or two thick may be observed) and the increased prominence of its structural features, notably the *steeply inclined bedding* (*10° to 20°*), the numerous erosion planes, abundant cross-bedding, etc. Its thickness is usually about 100 feet, but may reach 150 feet over the center of the province.

Areally, this member extends laterally beyond the lower members, whenever it can be followed far enough to determine the point. It persists to the eastward with complete loss of structure except normal horizontal bedding into the eastern part of Fairfield County until it passes below drainage, where it is frequently reported in wells with "shales" below it. It is found capping the hills almost as far west as Amanda (Fairfield County) and Tarleton (Pickaway County) but beyond that it is removed by erosion. It is not found more than three or four miles north of Lancaster, the hills beyond that point falling away to lower elevations.

In the southwest corner of Hocking County (Salt Creek Township) and the northeast corner of Ross, and in the western townships of Vinton County, the horizon of the Black Hand is so low in the hills that its passage westward, first into sandstones and then into the shales of the Cuyahoga, can be traced with ease. A marine fauna appears in the sandstones just east of where they pass into shale. The transition has been traced at several points, sufficient to show that the zone of transition extends a distance of 15 miles in a south, slightly southeasterly direction from near the extreme northeast corner of Ross County to near Raysville on the

south line of Vinton County. It has not been traced into Jackson County where a few miles farther to the southward it must pass below drainage.

Over the center of the province, the Black Hand is a coarse pebbly sandstone with occasional beds of conglomerate. The pebbles, all quartz, seldom exceed an inch and a half in diameter. The most striking feature of the member is the bedding, which is inclined at angles ranging commonly from 10° to 20° and sometimes reaching 25° or even more. This structure is much more prominent on the eastern side of the area. This inclination is found throughout most of the thickness of the Black Hand, only the topmost 10–25 feet lying horizontally. The inclined beds correspond in a way to the foreset beds of a delta, the horizontal beds above to the top-set beds. The inclination is almost always toward the northward or at least with a northerly component.

When all the features of the Black Hand and Fairfield members over the area of the facies are taken into consideration, it is evident that the members are distinct. Yet it may be difficult to draw the line between them in any given section, especially in the southern part of the area in western Hocking County. It is impossible here to discuss the relation of one bed to the other. Owing to the physical nature of the members, the contact is almost always covered except for short exposures of a few feet at wide intervals. Where the members are well developed there is almost invariably an erosion plane present at or near this contact. But whether this is a plane of unconformity between the two members or is merely another of the commonly observed erosion surfaces, several of which can sometimes be seen in a single outcrop and most of which are obviously local, is not yet fully determined. In any event the erosion plane, if there is an extensive one, disappears near the margin of the facies as the coarse sediments give place to shales, and is believed to be of no great significance. Whether these conglomerate facies be regarded as deltas of a peculiar type or as bar formations, the surface of the accumulation at any given time stood well above the mud floor of the adjacent shale facies and was liable to erosion over portions of its surface under conditions which would not affect the adjoining deeper areas.

G. F. Lamb has described two conglomerate horizons in Wayne County in northern Ohio.[1] Both have the bedding inclined to the northward, and erosion surfaces are recorded beneath each and are described as unconformities. The lower bed is from 2 to 45 feet thick and is about 625 feet above the Berea sandstone. From this it would appear to be near the horizon of the Black Hand member. It may, however, be the Berne member (which in places is Herrick's Conglomerate I recorded by Herrick in northern Ohio) which was also preceded by erosion over the central Ohio conglomerate areas, and which extends areally beyond the Black Hand both in the Granville facies and on the western side of the Hocking Valley facies.

The Berne member, never over 20 feet thick, and frequently only one foot in thickness, is always present and readily recognized, resting on the Black Hand. The term is proposed from numerous outcrops in Berne Township of Fairfield County. In the Hocking Valley region, as in the Toboso region, this bed consists largely of pebbles, but sandstones of moderate coarseness and shales are found in it at some localities. In mapping, its upper limit forms the logical plane to be followed since it usually forms the top of the ledges and the bed is lithologically very like the underlying conglomerates. The contour of the surface of this bed, that is, the surface of the Cuyahoga deposits, is much the same as that of the Black Hand member, but in order to understand the Berne member it is desirable that the top of the Black Hand be distinguished and that the contour of its surface be determined separately from that of the Berne member, thin though the latter be.

The topographic map is essential to the determination of these features, and at the time the field work on this region was done the Lancaster and Logan sheets were the only ones issued covering any considerable portion of the area. The Chillicothe sheet which lies southwest of the Lancaster sheet, covers only a very small area of the transition zone on the extreme western side of the province. Much of the most interesting part of the province in southern Hocking and the western part of Vinton counties lies south of the

[1] "Middle Mississippian Unconformities and Conglomerates in Northern Ohio," *Ohio Naturalist*, XIV (1914), 344–46.

Lancaster sheet and has not been visited since 1910, when it was unmapped.

On the eastern side of the main body of the facies, that is, that portion of it lying west of the Hocking River, the top of the Black Hand dips to the eastward at a rate which varies considerably from point to point, but is much greater than the general regional dip. In north-central Hocking County the dip over much of this side is about 35 feet per mile, but reaches a rate of 119 feet for a distance of a mile on the eastern flank, just west of Hocking River. A few miles north of this, the dip is about 37 feet per mile over the center of the conglomerate area, increasing to an average of 58 feet over most of the eastern flank, but with no indication of the extreme dip observed for the short distance farther south. Along the eastern margin of this steep slope the surface of the Cuyahoga is carried down nearly to the level of the main drainage lines, but after continuing for a short distance thus, it recovers and rises to the eastward in a broad low arch a few miles wide, within which cliffs of Black Hand 40 or 50 feet high are exposed; beyond this to the eastward it sinks rapidly below drainage. This broad low arch is exposed for four or five miles along the Hocking River above Logan and again along Rush Creek in Hocking County several miles to the northward, as well as along the intermediate smaller streams. It is very like a broad, low anticlinal fold with its axis trending in a generally north-south direction. However, it does not appear probable that the doming of the surface is due to gentle regional warping, although this possibility has not been disproved. It seems more likely that this dome is a second smaller conglomerate mass lying a short distance east of, and nearly contiguous to, the main mass, and is, indeed, merely a lobe of the main Hocking Valley area. The structures observed in the exposed portions bear this out, the material being conglomerate with northerly dips. It probably dies out north of Rush Creek, for no trace of it was observed farther north and east of Lancaster where the sandstone loses its pebbles and structures immediately east of the Hocking River, and the surface declines regularly to the eastward. The contour of the upper surface of the Black Hand is thought to be due to the influence of this separate lobe of accumulation, for

the thickness of the entire Cuyahoga is greatest over this lobe and the main conglomerate area and diminishes somewhat in the slight sag between them.

The principal considerations in support of this are: (1) the lack of evidence of any pronounced anticlinal structure in the underlying rocks, although the region has been drilled over for years in the search for gas and oil; (2) the increased thickness of the Berne member in the trough and its diminished thickness over the crests; the same is true to some extent of the next succeeding bed, the Byer member of the Logan.

On the western side of the Hocking Valley province, the inclination of the top of the Black Hand (and with it the Berne member, which is uniformly thin) becomes considerably lessened and the member may even sink slightly to the westward, notwithstanding the general regional rise of the older rocks in that direction. At the Rock House, about 11 miles west of Logan and just south of the south edge of the Lancaster sheet, the elevation of the top of the Cuyahoga, that is the top of the Berne member, is 1,060 feet above sea level. Eight and one-half miles almost due southwest of this point on the Ross-Hocking county line, the same horizon occurs at only 975 feet, a decline of 85 feet contrary to the general regional dip. The decline in the surface of the formation is here clearly due to the westwardly decrease in thickness of the Cuyahoga.

The Berne member differs very decidedly from the conglomerates lower down in the presence of a marine fauna. This is seldom abundant, either in species or in individuals, but the fossils are so widespread, both in the finer beds and in coarse conglomerates, that they may be considered an essential character.

In the region of the Hocking Valley facies, it is found in its simplest form over the central and western portions. Here, with a few exceptions, it is a more or less massive coarse sandstone with abundant pebbles, on the whole always decidedly coarser than the Black Hand, and usually from one to three feet thick. It becomes thinner westward so that it is usually about one foot thick on the western margin of the region. It even extends westward for a few miles beyond where the Black Hand becomes shaly and in

eastern Ross County is found resting on typical Cuyahoga shales, itself reduced to a horizon of a few inches of soft clay shale or clay ironstone with many small quartz pebbles imbedded therein. It does not pass into sandstone before its final disappearance; it is a pebble bed up to the point of its disappearance.

The Berne member attains its greatest known thickness in the trough between the two domes of conglomerates mentioned above, where, near Enterprise in Hocking County, it is at least 16 and probably 20 feet thick. It there consists of many thin beds of fine pebbles alternating with thin beds of sandstone of varying coarseness, the whole suggesting aggradation of different kinds of material brought by continually shifting currents from the more exposed, shallower portions of the adjacent conglomerate masses to the more sheltered deeper water between them. The member, here and over its entire area, can best be interpreted as the concentrate of pebbles and coarse sand which resulted from the reworking of the top of the earlier deposits by wave and current action. This must have happened soon after the completion of the deposition of the underlying conglomerates and while they were but slightly consolidated.

It is not certain whether the Berne member should be considered the topmost member of the Cuyahoga or the base of the Logan formation. Lithologically it falls readily with the Cuyahoga conglomerates, and in the event of mapping the region it will prove a most convenient upper boundary. There is very good reason to believe, however, that from the point of view of historical succession it belongs with the Logan. This conclusion is supported by several considerations. (1) The base of the bed is sharp, and in places is undoubtedly a plane of erosion as where, near Logan, the horizontal beds of the top of the Black Hand have been removed and the Berne member truncates the inclined beds of the Black Hand. (2) There is occasionally a transition from the Berne member to the Logan although never more than a few inches thick, as in the railroad cut at Hanover (Licking County) and at localities in Hocking County. (3) Beds very like the lower member of the Logan, although usually somewhat coarser, are frequently present in the Berne member east of the Hocking Valley province. (4) The

bed is a marine conglomerate, as shown by the general occurrence of marine fossils in it. Although the body of the Cuyahoga conglomerates is not to be considered as typically non-marine, it is evident, from the lack of all fossils except trails, that it was a very specialized type of marine deposit. The Berne member marks the resumption of conditions under which marine life could exist. (5) The faunas found in the Berne show much closer relationships to those of the Byer member of the Logan than to those of the Black Hand in its marginal transition phases. These faunas do not, however, appear to indicate an essential difference in age. The evidence goes to show that the Black Hand and Logan faunas were contemporary and their distinctness is due to facial differences. The fauna of the Berne member thus indicates the existence of faunal conditions like those of the superjacent Logan rather than those of the subjacent Black Hand.

In concluding the consideration of the Hocking Valley region, it remains to be said that the source of its material must have been in the same direction as that of the Toboso province. The gentle northeastward inclination of the sandstone beds of the Fairfield member on the east side, their occasional westerly dips on the west side, the bedding of the Black Hand sharply inclined to the east, northeast, north, or west, when considered with the southeasterly trend of the axis and the shale areas to the east and west, clearly indicate that the source of the material was to the southeast.

The material of the Cuyahoga sandstones in both the Hocking Valley and the Toboso provinces is quite pure quartz sand and pebbles. Close examination of the crushed rock from the Black Hand shows some small amounts of feldspar and more abundant kaolin, the latter clearly indicating the once greater percentage of the former, but it appears that the material has been much worked to bring it to its present degree of purity. It is true, however, that the samples so examined were selected for their purity in connection with work on glass sands. In the Fairfield member and less rarely in the Black Hand, beds may occasionally be found in which the kaolin is so abundant as to be readily detected in the field without the aid of a lens. These beds must have been quite high in feldspar originally.

THE GRANVILLE SHALE FACIES

Extent and thickness.—This facies lies between the Toboso and Hocking Valley conglomerate facies and is an area in which shales accumulated to a much greater extent than in the other two. It is of unusual interest because it was in the Licking County outcrops of this facies that Herrick worked out certain of his faunal horizons and from which he described many species; furthermore the succession of formations found there, as interpreted by the workers of the time, has been adopted during the past decade as the typical Waverly column of Ohio.

The boundaries of the facies are only partially determined and must be largely inferred at present. In general it appears to occupy most of the eastern half of Fairfield and the western part of Perry counties, where it is almost entirely below drainage, and the central part of southern Licking County. The Toboso conglomerate area lies to the eastward in Licking County and, presumably, also in Perry County, but deep under cover in the latter. The Hocking Valley conglomerate area lies to the westward in central Fairfield County, and its hypothetical northward extension in northern Fairfield and western Licking counties, since removed, is supposed to have limited the Granville province in that direction. To the southeastward, it is partially limited by the small conglomerate lobe on the eastern side of the Hocking Valley area, and it probably does not extend much farther in that direction under the Coal Measures cover before it is bounded by coarse sediments extending continuously from the Toboso to the Hocking Valley facies. It has not been traced to the northward and northwestward, but it probably extends across the northern part of Licking County and somewhere in that direction it formerly united with the shale deposits of the Cuyahoga which, from theoretical considerations, must have extended around the northern end of the Hocking Valley conglomerate facies and must have been continuous with the shales of the Scioto Valley shale facies.

Unfortunately the three northern townships of Fairfield County are almost without exception very heavily drift covered, a buried pre-glacial valley; the northwestern portion of Perry County, although underlain by rock, shows very few outcrops, and at the

most, only the topmost beds of the Cuyahoga are shown. In addition, Licking County southwest of Granville is practically unexamined by the writer.

Wherever this facies has been observed, either in the outcrops or by means of well-records, its sediments show the effect of the conglomerate areas on either side. Their thickness, while somewhat less than in the adjacent conglomerate facies, is much greater than in the Scioto Valley shale facies, and the sandstone content appears to be decidedly greater. As has been stated, the thickness of the Cuyahoga in the Hocking Valley facies is from 600 to 625 feet. Passing eastward this gradually decreases in the wells to about 500 feet just west of Bremen in Fairfield County (Myers well). A few miles to the northward at Rushville, an approximate determination with several somewhat uncertain factors gives 535 feet. At Newark, yet farther north in Licking County, well-records indicate about 570 or 575 feet, and at the Everett quarry over the Toboso facies, due east of Newark, it is 588 feet thick. This series of observations extends in an irregular oblique line north and northeasterly, entirely across the Granville province. Newark, from various considerations, appears to lie on the transition to the Toboso facies.

The Black Hand member appears to be generally present along the length of this line, although there are often unknown covered intervals of several miles for which no well-records or outcrops are known. It appears to be from 50 to 100 feet thick and is considerably changed from its conglomerate phase; it consists largely of coarse or moderately coarse sandstones, with occasional shaly beds, and sometimes carries fossils. Just east of Rushville, there is good evidence from wells that the Black Hand is largely represented by what the drillers report as shale.

Due westward from Newark a change in the nature of the Black Hand can be observed in the surface outcrops. Within four miles it passes largely into sandy shales; sandstone beds are present, sometimes two or three feet thick, but they are irregular and may pinch out entirely in a few feet. This passage to shales exactly parallels that observed at many points on the western side of the Hocking Valley facies in Hocking, Vinton, and Ross counties.

Conditions of outcrop, and limited observation, however, have not permitted the tracing of this passage farther in Licking County. The nature of the Black Hand horizon at Granville, two or three miles yet farther west, is not known, but a further disappearance of the sandstones is anticipated. In fact, so firm is this conviction that no hesitation has been felt in adopting the name Granville for the shale province although very little of the Cuyahoga was seen by the writer in that vicinity. Four or five miles yet farther to the westward on Moot's Run, the fossiliferous beds of the Cuyahoga, there largely a shale but with considerable sandstone, furnish an excellent collecting ground; whether they are Black Hand, shale facies, or belong to the underlying Raccoon member is not yet determined.

Raccoon member.—Below the Black Hand near Newark there are some 20 or 30 feet of sandy or clay shales with numerous thin sandstones, sometimes quite fossiliferous; the remainder of the Cuyahoga, here and other points known to the writer, is below drainage and is commonly reported as shale by the drillers, but an occasional more careful record shows that the next underlying 200 feet carry many beds of sandstone, sometimes 3 to 6 feet thick, with thicker shale beds. The lowermost 200 feet, more or less, appear to consist almost wholly of shale. In 1878, when Hicks proposed the name Black Hand, he used the name Raccoon for the shales between it and the Sunbury shale. When, later, the central Ohio and northern Ohio Waverly formations were correlated, it appeared that this term was synonymous with Cuyahoga and it was dropped. It may be brought forward, temporarily at least, to designate that almost unknown thickness of shales and sandstones below the Black Hand member. So little is known of these at present in the Granville facies that it cannot yet be safely urged as a permanent formational name.

The Berne member.—Little need be said of this member in this province. It is a pebble bed of essentially the same composition as over the two conglomerate provinces, except that beds of finer-grained sandstone are frequently intercalated. Between the two conglomerate facies there is an interval of 20 miles in northern Fairfield and southern Licking counties across which its presence

has not been shown because of drift-covered outcrops or its occurrence below drainage, but it is probably present. Followed westward from the Toboso province it can be traced readily into the Conglomerate I of Herrick in the section in Quarry Run at Newark. At the Dugway three miles west of Newark, where the Black Hand member is largely shaly, the Berne member is 10 feet thick and the pebbles are noticeably smaller than to the eastward.

The section in the Quarry Run at Newark has become the classic section of the upper Waverly of Ohio. Prosser's description of this section[1] in which he adopted the stratigraphic units used by Hicks[2] and Herrick has been accepted as the standard column of the upper Waverly, and most of the correlations that have been made with the upper portion of the Waverly have been based thereon. It is, indeed, the only section of this portion of the scale which has been accurately described. It appears, however, that the Black Hand has been made to include too much in the descriptions of this section. Only the lower 60 feet are the equivalent of the Black Hand as that member is interpreted in the present work. Conglomerate I of Herrick, which was placed by Prosser 29 feet below the top of the Black Hand, is the Berne member and the top of the Cuyahoga. These 29 feet are to be correlated with the Byer member and the lower part of the Allensville member of the Logan. Prosser's error is the result of his having accepted Hicks's statement that all of these beds were the equivalent of his (Hicks's) Black Hand at Clay Lick and Toboso. To Hicks belongs the credit of having first appreciated the passage of the Black Hand conglomerates into finer-grained sediments to the westward. If Orton had appreciated the significance of Hicks's discovery, much of the confusion of later years would have been spared.

[1] *Jour. Geol.*, IX (1901), 221–26; *Am. Geol.*, XXXIV (1904) 358–61.

[2] *Am. Jour. Sci.*, 3d ser., XVI (1878), 216.

[*To be continued*]

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